MOVEMENTS OF FLOATING DEBRIS IN THE NORTH PACIFIC

Satsuki Matsumura
National Research Institute of Far Seas Fisheries
Fisheries Agency, the Government of Japan
Shimizu-shi, Shizuoka, 424 Japan

Yoshinobu Wakata and Yasuhiro Sugimori
Faculty of Marine Science and Technology
Tokai University
Shimizu-shi, Shizuoka, 424 Japan

ABSTRACT

A net fragments tracking experiment and numerical simulations using surface current data set (SCUDS) data were conducted to estimate movements of floating debris in the North Pacific.

Six driftnet sets (40 tans each) were placed in the area lat. 39°N, long. 155°E. Locations of the net sets and sea surface temperatures were collected and transmitted every day using the Argos system. Data were taken about six times a day for 4 months. At termination of the net drifting experiment, the net sets with buoys were retrieved and new Argos buoys with curtain drogues were released at the points of retrieval to continue the surface current tracking.

The buoys moved predominantly eastward, although each track line was complicated, particularly in areas near the Oyashio Front. It is considered that the movements of the nets were mainly due to surface currents and that direct influence from wind was negligible, because the underwater portion was very large (a driftnet 2,000 m long although it had formed a mass) compared with the above-water portion of the buoy. Average speed was estimated based on the buoy movements and ranged from 10 km/day to 20 km/day. Movements of floating debris in the North Pacific were simulated using a computer model based on SCUDS.

Results showed the existence of two large-scale eddies in the eastern and western parts of the mid-Pacific, and floating debris are through to accumulate in these areas.

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INTRODUCTION

North Pacific currents are found in a great circle ranging from the Kuroshio through the Kuroshio Extension and the North Pacific Current to the California Current and the North Equatorial Current in the south. In the vicinity of these currents are the Oyashio, Alaska, Aleutian, and other currents.

Floating debris (excluding Styrofoam, which is mostly above the surface) moves along these currents. Movements change depending on large and small vortexes in the water and are difficult to generalize, but we can estimate average movements on the basis of surface currents.

Marine features of the North Pacific are outlined by Favorite et al. (1976). The northwestern part of the North Pacific is characterized by the Kuroshio Extension and the Oyashio. The distribution of water masses in summer is greatly affected by the southerly intrusion of cold water masses and the strength of the Aleutian Current, both of which vary from year to year, as reported by Hiramatsu (1987, 1988).

Tests using driftnets were conducted to estimate movements of floating of floating debris. Driftnets were set in the Oyashio waters in May 1988 and were recovered after about 4 months of drifting. The Argos system was used for tracking the nets and analyzing their drift routes. We have also illustrated overall currents on a computer display using the surface current data sets (SCUDS), which covers ship drift data from about 4 million ship observations over the past 40 years.

CURRENT OBSERVATIONS USING ARGOS BUOYS

Method

Six driftnets were set by the first survey ship in order to observe changes in net shapes and movements in the northwestern part of the North Pacific. Each net was equipped with an Argos buoy at one tip and a radio buoy at the other. Nets were set in waters at lat. 39°N, long. 155°E and were arranged in the shape of a star, with five nets set in a 37-km (20-mi) radius from a key net.

Each net was 2,000 m (40 tans) long. Their fluid resistance in the water was so large that the early movements of each net were presumed to indicate an average current over a distance of 2,000 m. Ten days later, the shapes of several nets had changed greatly. Some nets were either folded or "balled up." They became masses with a maximum length of roughly 50 m (Mio et al. 1990).

They were still large enough to resist winds, and buoy tracks accurately indicated the movements of nets in the sea currents. There was a thermometer inside each buoy case. The buoy was metallic and had no heat-resistant structure. Therefore, each thermometer was able to indicate surface water temperatures. Styrofoam was used as a floater at the upper part of each buoy. It reduced heat flow from sunlight. Even if the buoy was exposed to strong sunlight, the thermometer's deviation from surface water temperature would have been very small.

Argos buoys were set on 5 and 6 May 1988. Three of the six buoys suspended transmission during drifting because of mechanical troubles, but the second survey ship recovered three of the four trouble-hit Argos buoys 4 months later by tracking radio buoys. The second survey ship recovered the nets and released three Argos buoys with curtain drogues for further observation of currents.

Results and Analysis

Tracks of buoys from May to September are illustrated in Figure 1.

Buoy 4783, which moved the greatest distance eastward in the 4 months, reach long. 180°. The slowest-moving buoy (4782) came as far as long. 162°E. An average speed of the maximum eastward movement was about 20 km/day. Any buoy movement was not straight but very complex depending on inertial forces and tides. The theoretically calculated inertial cycle at lat. 40°N is about 19 h, and it matched these observations. Figures 2-4 indicate the track of buoy 4789, which is zoomed gradually. Figure 4, where vertical and horizontal scales are almost the same, shows that the floating debris moved north to northeast at an average speed of 7 cm/sec while making a clockwise motion. The radius of the circular motion was about 1.6 km, and the flow speed was 10-50 cm/sec. Driftnets, which were set at roughly the same place, followed very different tracks, hinting at a large diffusion coefficient in the waters. One hundred days after setting, the maximum east-west distance between tracks was 1,637 km and the maximum

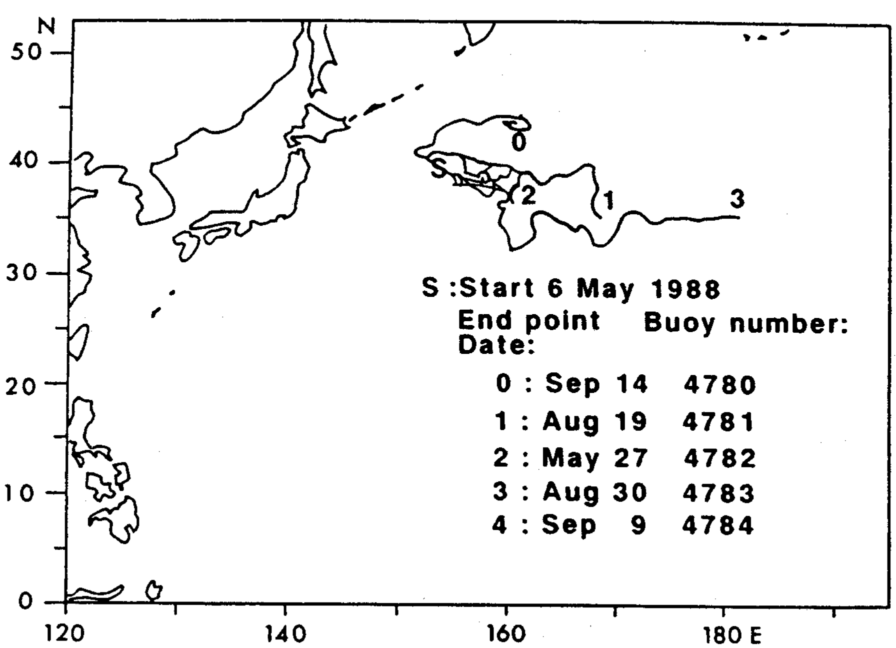

Figure 1.--Trajectories of drifting buoys.

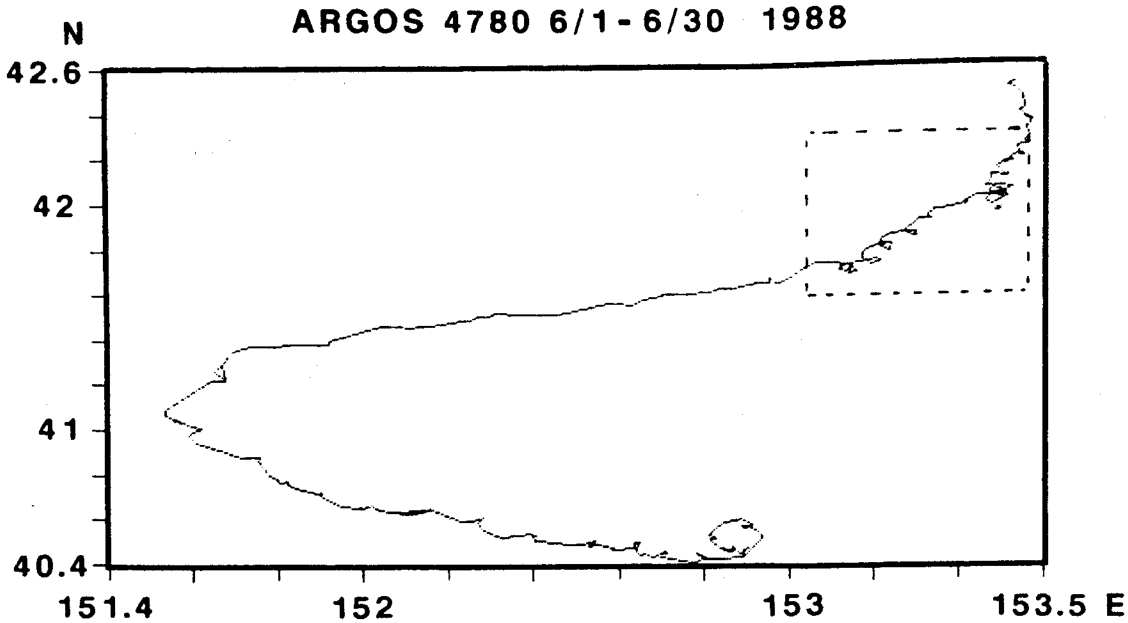

Figure 2.--Western part of buoy 4780 trajectory.

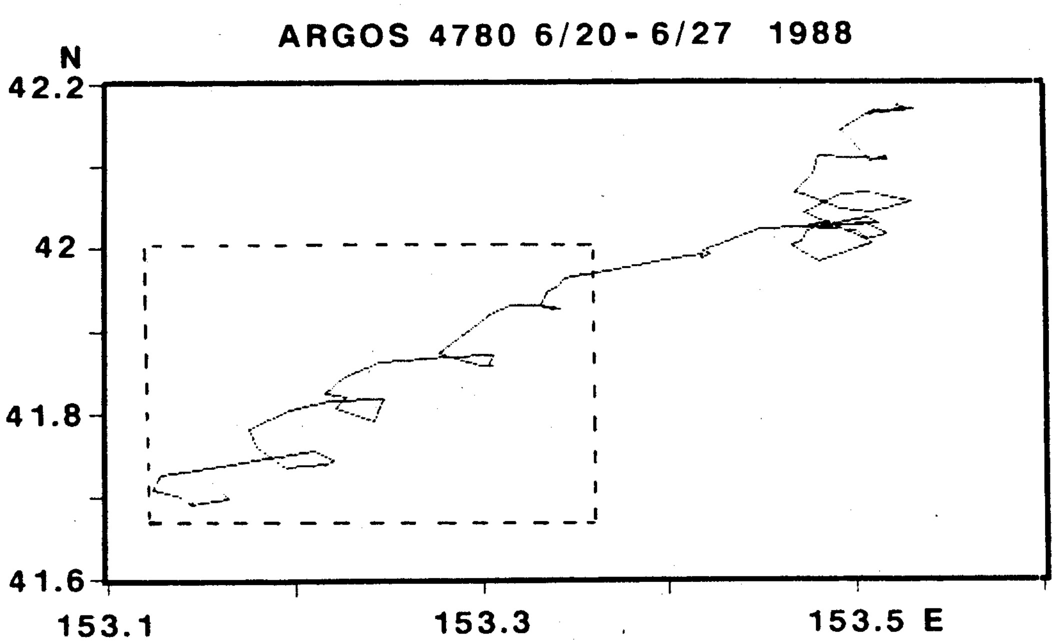

Figure 3.--Part of buoy 4780 trajectory, enlarged from Figure 2.

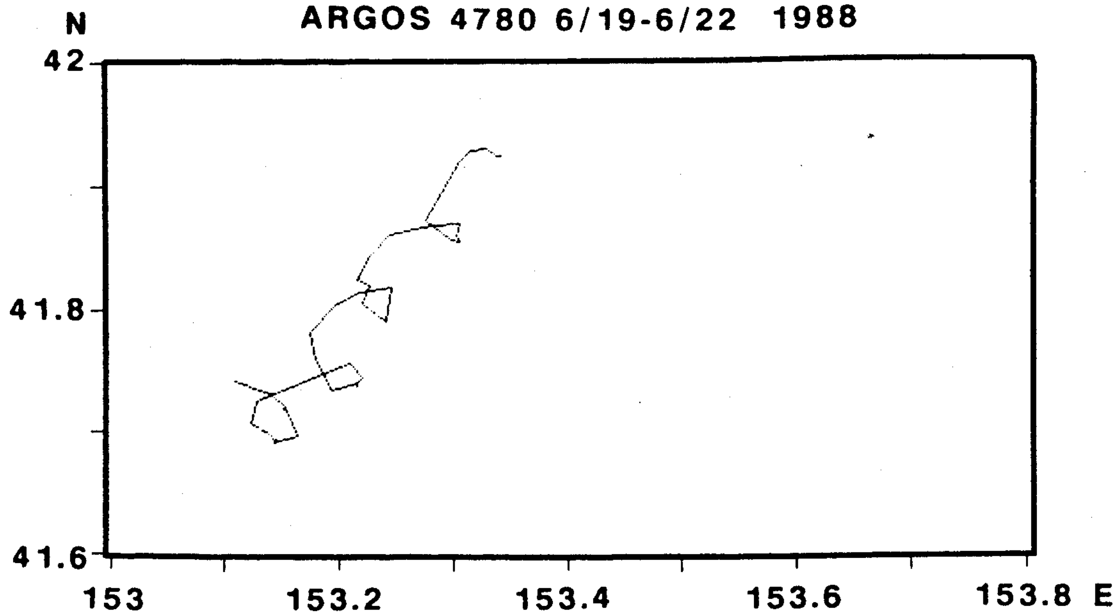

Figure 4.--Inertia circle of buoy 4780, enlarged from Figure 3.

north-south distance was 1,021 km. The large diffusion indicates a need to incorporate a large plus or minus deviation in forecasting the movement of any object in the water on the basis of the generally known currents. The large diffusion coefficient gives evidence of great turbulence in the waters.

Data from thermometers on the buoys are shown in Figure 5. Any buoy with a large net cannot be expected to go through a water mass or across the front of a mass. Short-term changes in the water temperature, especially sudden declines, may be attributable to vertical mixing of waters.

The water temperature rose gradually during the observation period between May and September. Any sudden rise in the temperature may be attributed to a combination of strong sunlight and calm water, which can cause an increase in just the surface water temperature. It may also be ascribed to surface water which was heated by the sun and flowed into the vicinity of a buoy.

Driftnets remained at a depth of 10 m. Warm surface waters which are frequently seen in the northern part of the North Pacific in summer are usually limited to 1 or 2 m in depth.

The surface water temperature changes are seen frequently in infrared heat pictures taken by satellites and have some adverse effect on analysis of water masses, which depends on surface temperature.

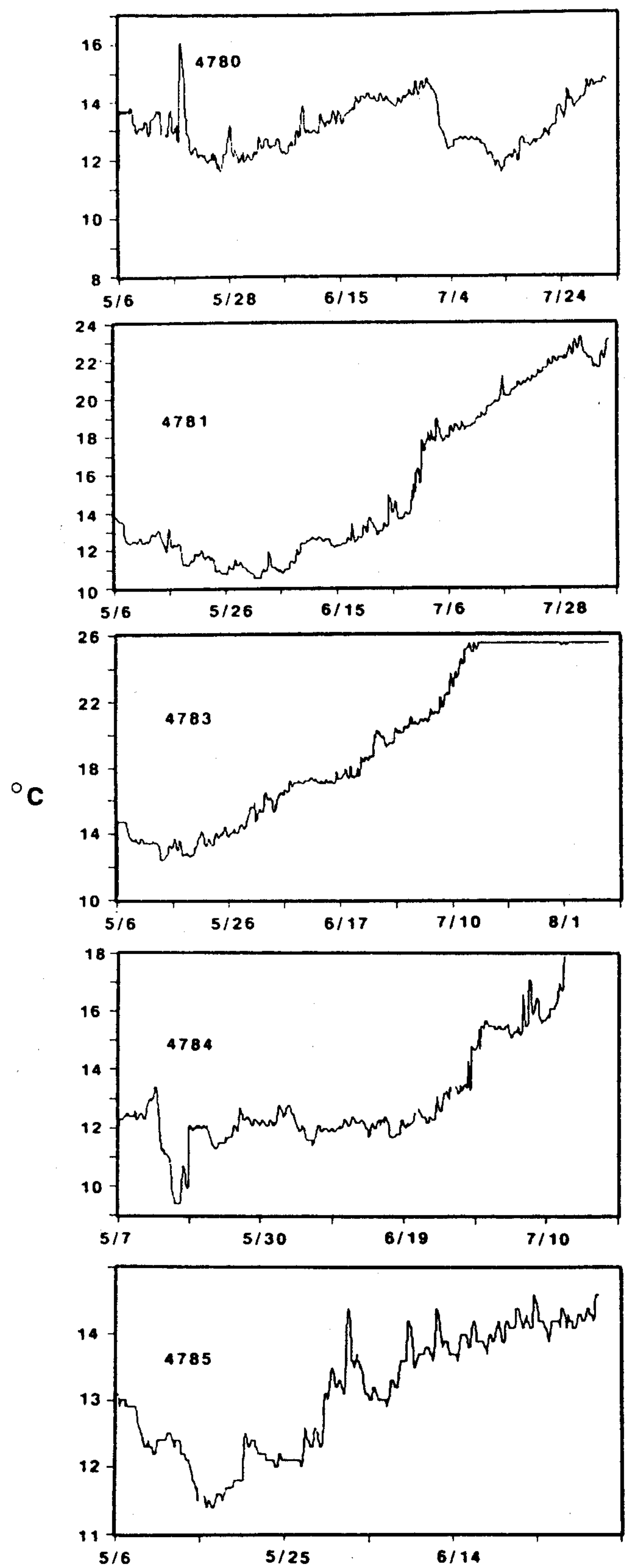

Figure 5.--Daily changes in buoy temperatures (May-August 1988).

SIMULATION OF FLOATING DEBRIS MOVEMENT AND DEBRIS DENSITY USING SHIP DRIFT DATA

If the speeds of all sea currents in time and space are available, the track of floating debris like the buoy on currents such as those discussed in the previous section can be simulated. Based on a specific speed at an initial point, we can determine a point debris would reach within a given period of time. Another current speed at the arrival point can be used to estimate how fast and where the debris would move further. Repeating such estimates can lead to a possible track which floating debris would follow.

In this section, we try to solve the Lagrangean equation and simulate a buoy track on the basis of given sea current speeds. We have used the ship drift data released by Meehl (1982). The currents in any time and space can be obtained by interpolating these data. We have compared the simulated results with findings from buoy drift observations by Kirwan et al. (1978) and sightings of floating debris observed by the Fisheries Agency, the Government of Japan (Mio et al. 1990) in order to analyze the mechanism for the gathering of objects.

Our simulation results successfully matched the findings from Kirwan's observation in both time and space. The model may be available for the simulation of buoy movement.

Thus, in the following, we will discuss where buoys set in waters around Japan move and where a number of buoys set all over the Earth would gather.

Drifting in the Western North Pacific

Assume that buoys are initially dropped at lat. 30°N, long. 140°W near Torishima Island in the western part of the North Pacific. The results show how the buoy track changes depending on the season.

Spring

Figure 6(a) shows the track of a buoy set on 1 April. The buoy immediately begins to move eastward and reaches the international dateline in 6 months. However, the buoy remains around lat. 30°N, long. 150°W for nearly 2 years while its track loops. This is because it is dragged into a vortex in the eastern part of the North Pacific (Meehl 1982, fig. 2). Floating debris can remain in the water for a long time. If floating debris such as waste were dumped evenly all over the Pacific, it would tend to gather in the vortex waters.

Summer

Figure 6(b) shows the track of a buoy set on 1 July. It also moves eastward, but its speed is far faster than that of the spring buoy. It reaches the international dateline in about 4 months. Since the speed of currents at long. 140°E is fastest in autumn, the buoy set in summer is eventually moved by these fast currents. Later, it is dragged into the vortex in the eastern Pacific and remains just north of Hawaii.

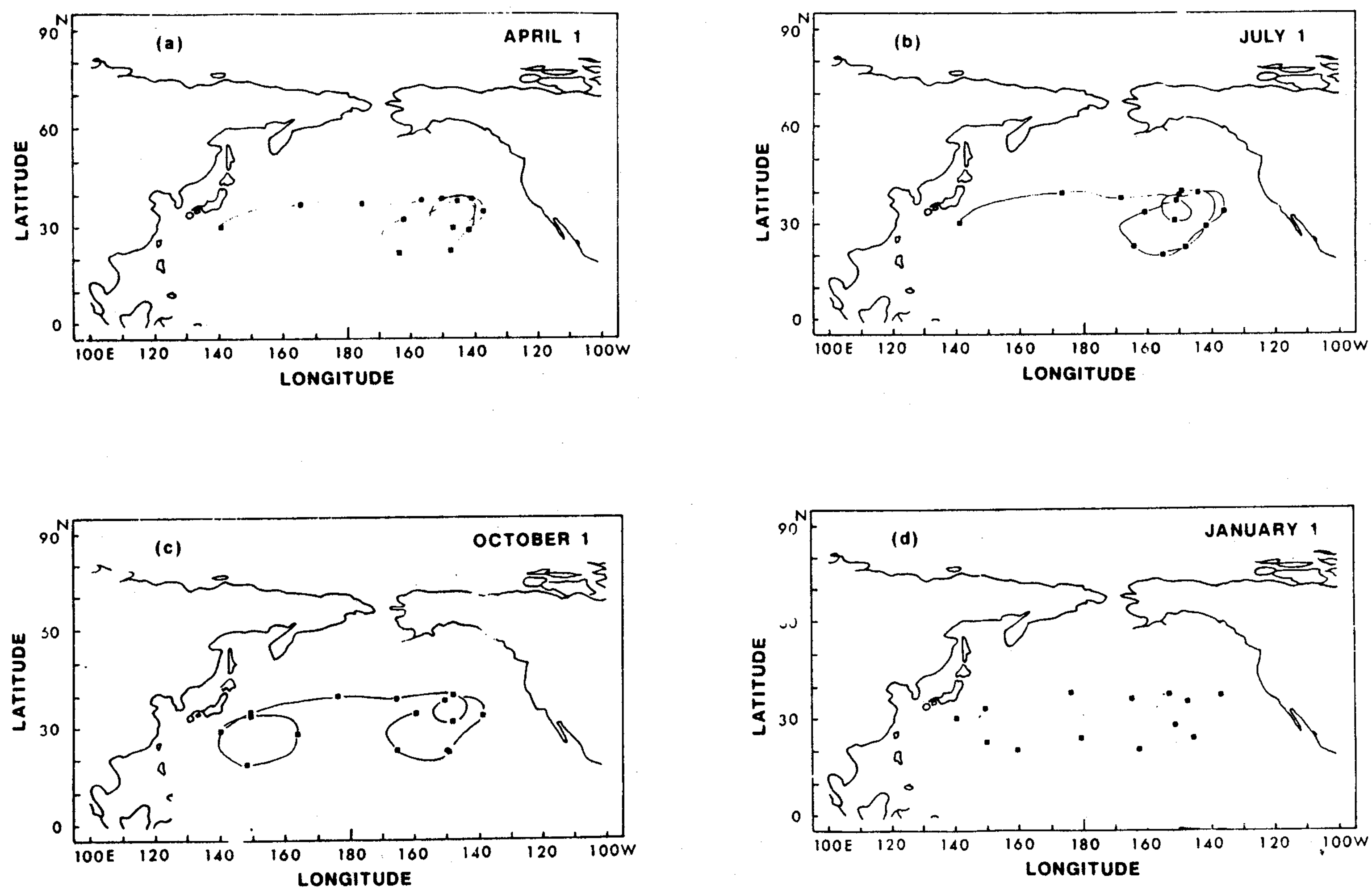

Figure 6.--Simulated tracks of buoys which were set at lat. 30°N, long. 140°E in the western North Pacific in (a) spring (1 April), (b) summer (1 July), (c) autumn (1 October), and (d) winter (1 January). Each buoy took 3 months to move from one mark to another.

Autumn

The track in Figure 6(c) is for a buoy set 1 October. Unlike the above tracks, this one loops around lat. 30°N, long. 150°E before extending eastward. The Kuroshio Extension weakens, and a vortex and a southward current around lat. 30°N, long. 150°E appear in winter. A buoy dropped in autumn is dragged into this winter current. The loop indicates that floating debris stays in the water for a long time.

Winter

Figure 6(d) shows the track of a buoy put into the water on 1 January. Like the track of a buoy set in autumn, the winter buoy track includes a small loop in the western Pacific.

All of the above tracks loop in the eastern part of the North Pacific. This indicates that floating debris remains in the water for a long time and tends to gather there.

Drifting in the Eastern North Pacific

Figure 7(a,b,c) shows the tracks of buoys put into the water on 1 May. The three drop sites are lat. 50°N, long. 140°W; lat. 40°N, long. 130°W; and lat. 30°N, long. 120°W, respectively. The buoy in Figure 7(a) is set in the region of the Alaskan current system. It moves westward, traveling south of the Aleutian Islands around the Alaskan gyre and western subarctic gyre. After turning south it is picked up by the North Pacific current system and moves eastward as in Figure 6.

The buoy which is set at lat. 40°N (Fig. 7b) is carried westward by the North Equatorial Current system after remaining in the vicinity of lat. 30°N for nearly 2 years. The buoy set at lat. 30°N (Fig. 7c) immediately begins to move westward.

Debris Density

We calculated many tracks in the Pacific from starting points evenly distributed in space and time to find where buoys would gather. We tried to find not the place where a buoy dropped at a certain point would go, but the place where buoys would gather intrinsically due to currents, irrespective of setting points or time.

We simulated tracks for 7,755 buoys. Dropping points were chosen randomly so that the number of initial buoys would be the same for every unit area. The setting density was five buoys for every 3.09×10^{11} m^2 of ocean; buoy setting continued for 4 years. To scatter drop times evenly, they were chosen on the basis of random numbers. Presuming a lifespan of 2 years, we simulated a track for each buoy for 2 years.

Figure 8 indicates the debris density in January after 4 years of setting. In the sea, you see some points to which buoys were carried by currents. In the North Pacific, which is our area of concern, debris is

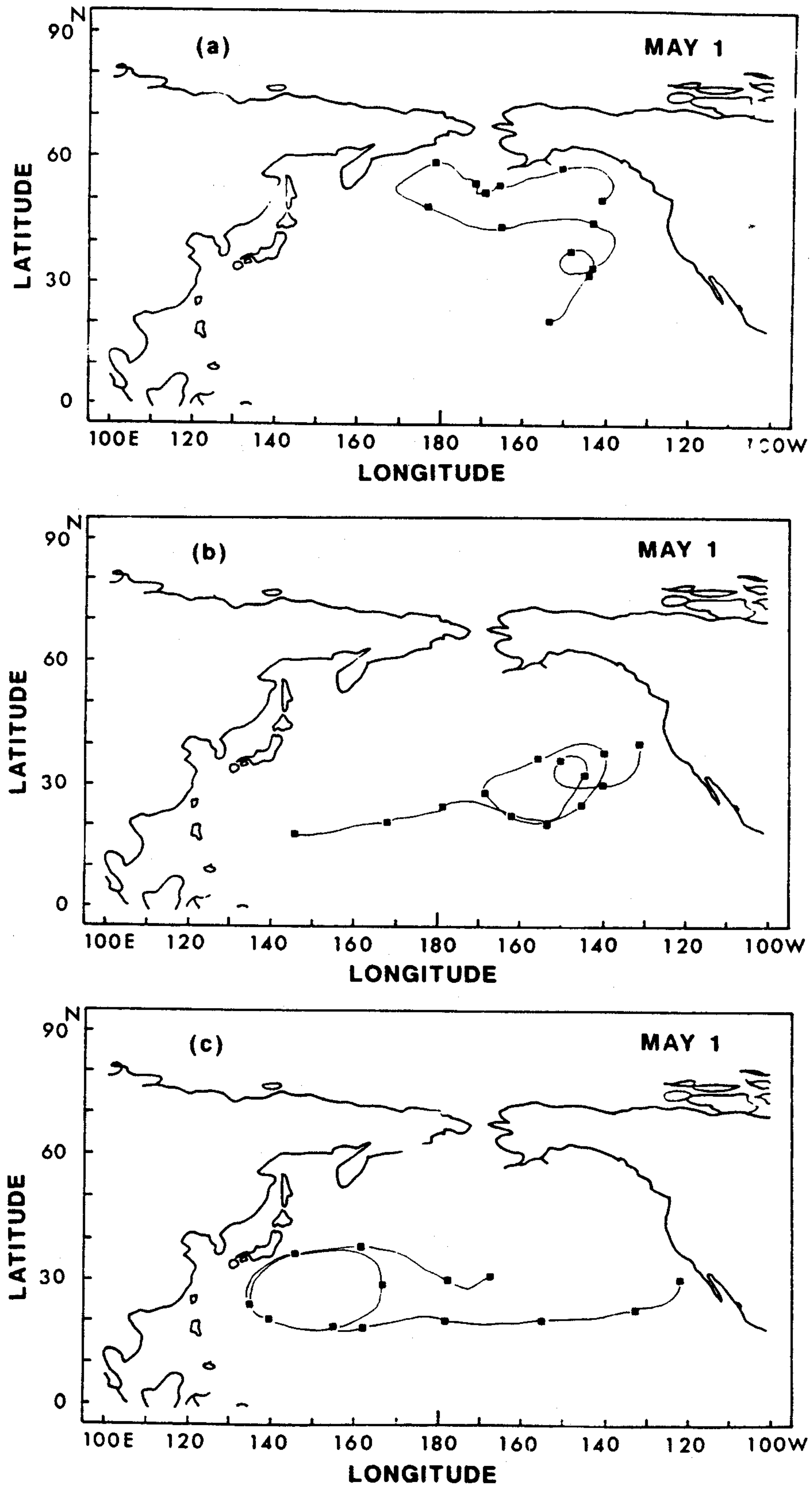

Figure 7.--Simulated tracks of buoys which were set at (a) lat. 50°N, long. 140°W; (b) lat. 40°N, long. 130°W, and (c) lat. 30°N, long. 120°W in the eastern part of the North Pacific on 1 May.

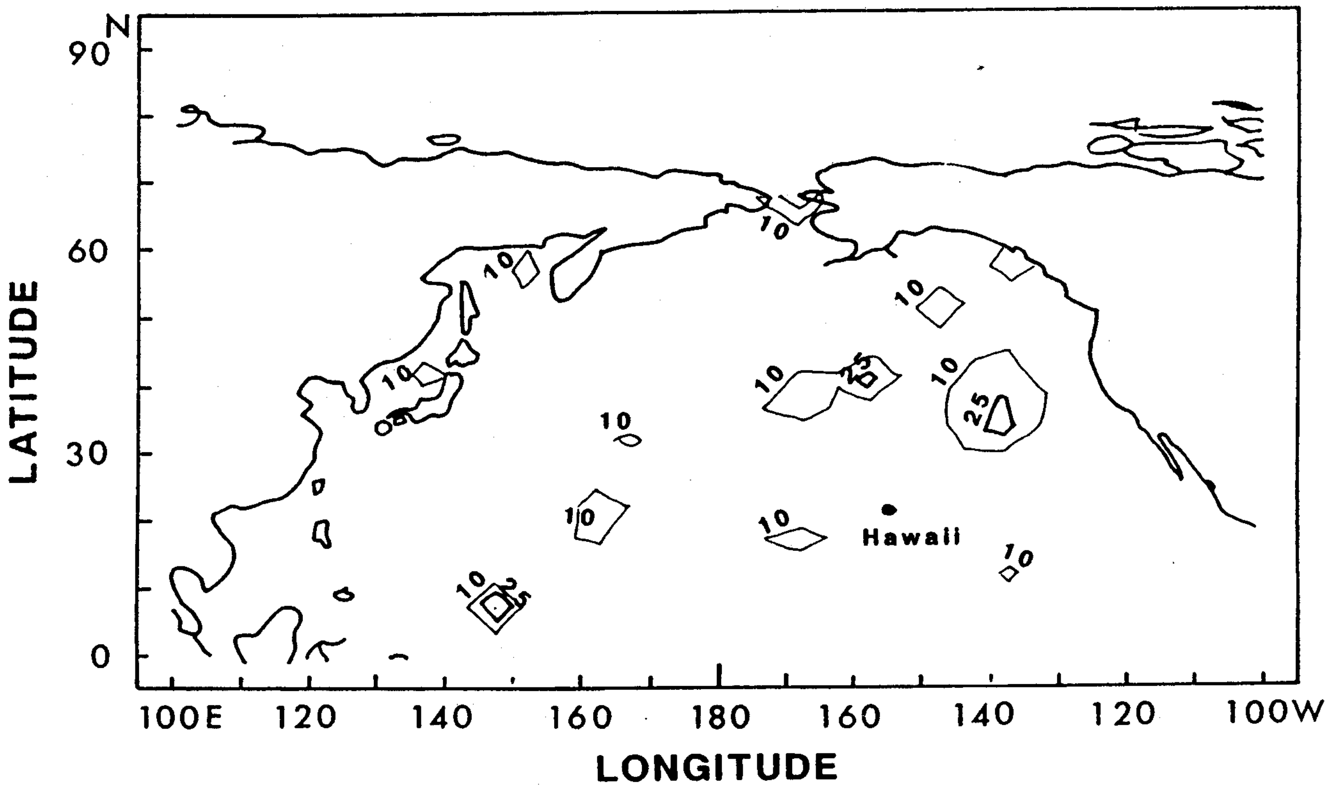

Figure 8.--Floating debris density in the North Pacific on 15 January. Contour line shows the number of buoys in unit area. Original density was give at every place.

seen to gather in the eastern part. The gathering points are to the north of Hawaii, which agrees with sighting observations of Mio et al. (1990). However, note that the gathering points shift seasonally. In the Northern Hemisphere, winds in areas of high atmospheric pressure circle to the right and sea surface currents deviate from the wind direction by 20° to 30°, as pointed out by McNally (1981). So we know that a high concentration of debris could be seen in the center of the North Pacific area of high atmospheric pressure.

CONCLUSION

The results of drift buoy observations matched fairly well those of the simulation based on ship drift data in waters like the Kuroshio Extension where the current is strong. Debris getting into the currents may cross the North Pacific in about 1 year.

There are no marked currents in waters around the Ogasawara Islands and northwest of Hawaii in any season. Figures for drift tracks and for distribution of floating debris point to those waters as locations where floating debris can gather.

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TYPE, SOURCE, AND ABUNDANCE OF TRAWL-CAUGHT MARINE DEBRIS OFF OREGON, IN THE EASTERN BERING SEA, AND IN NORTON SOUND IN 1988

Jeffrey A. June
Natural Resources Consultants, Inc.
4055 21st Avenue West
Seattle, Washington 98199, U.S.A.

ABSTRACT

In 1988, National Marine Fisheries Service scientists collected information on type, source, and abundance of marine debris caught during annual bottom trawl surveys off Oregon, in the eastern Bering Sea, and in Norton Sound. Numbers of individual debris items caught were tallied by haul. When possible, the nationality of origin was determined. Animals entangled or associated with debris items were noted. Debris items were categorized by material (e.g., plastic, glass) and use (e.g., galley wastes, fishing equipment). Effort in square kilometers trawled was calculated for each haul from distance fished and average net width measurements. Average catch-per-unit-effort (CPUE) in numbers of items per square kilometer was calculated for individual debris items, major categories, and total debris by area and for combined areas.

Of the 696 hauls surveyed, 70 were off Oregon, 541 in the eastern Bering Sea, and 85 in Norton Sound. Marine debris was most abundant off Oregon, occurring in 70% of the hauls and averaging 149.6 items/km^2. In the eastern Bering Sea, 23% of the hauls caught marine debris, for an average of 7.5 items/km^2. Norton Sound had the least amount of debris. It occurred in 7% of the hauls and averaged 1.9 items/km^2. Galley wastes dominated debris in Oregon (64% of the total CPUE) and in the eastern Bering Sea (40% of the total CPUE), followed by engineering/processing wastes. Fishing equipment debris was abundant in the eastern Bering Sea (1.86 items/km^2) and off Oregon (1.69 items/km^2), but was not found in Norton Sound. Plastic debris was found in all three areas, but was most abundant in the eastern Bering Sea. Debris of foreign origin accounted for 70% of the total CPUE of all debris found in the eastern Bering Sea; however, domestic debris dominated off Oregon (88% of the total CPUE) and in Norton Sound (100% of the total CPUE).

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INTRODUCTION

Marine debris, particularly plastic debris, has been identified as a potential threat to the marine environment world wide (Pruter 1987). To determine the magnitude of the problem, scientists must document the effects and abundance of different types of debris in the marine environment. Educators need to know the probable sources of marine debris in order to direct information campaigns at the proper audiences.

Prior to 1985, the majority of information about marine debris was anecdotal. Few studies presented scientific evidence on the abundance of marine debris or its effects on the marine environment. Recently, studies have reported on the effects of marine debris on marine mammals (Fowler 1988), marine birds (Day et al. 1985), marine turtles (Balazs 1985), and other marine wildlife (Pruter 1987).

While several studies have attempted to estimate the abundance of debris in the marine environment from at-sea disposal rates (Horseman 1982), few studies have addressed the abundance of marine debris using systematic methods. Quantitative surveys of marine debris deposited on beaches in Alaska have been conducted since 1980 (Merrell 1980; Johnson 1988). At-sea surveys have quantified floating debris in the North Pacific since 1977 (Shaw 1977; Dixon and Dixon 1983; Yagi and Nomura 1988). Berger and Armistead (1987) reported the number of pieces of net material caught in trawl nets deployed by foreign fishing vessels in the exclusive economic zone off Alaska between 1982 and 1984.

This study presents baseline information on the type, probable source, and abundance of marine debris caught on the seabed during bottom trawl surveys off Oregon, in the eastern Bering Sea, and in Norton Sound off Alaska during 1988.

METHODS

Survey Areas and Sampling Design

Marine debris was sampled by National Marine Fisheries Service (NMFS) scientists from bottom trawl hauls conducted during 1988 off the coast of Oregon in November-December, in the eastern Bering Sea from May to August, and in Norton Sound during August. A total of 696 hauls were completed covering 33.1 km² over a combined survey area of 907,851 km² (Table 1).

Seventy hauls were conducted between 45 and 110 km off the coast of Oregon between lat. 44° and 45°30'N and from 100 to 675 m deep (Fig. 1). The survey area off Oregon encompassed 7,230 km², of which 2.7 km² was actually covered by bottom trawls (Table 1).

In the eastern Bering Sea, 541 hauls were conducted from the 20 m isobath on the Alaskan coastline out to the 500 m isobath on the continental slope and north from the Alaska Peninsula to Saint Lawrence Island. Stations were sampled at the centers of 37 × 37 km (20 × 20 nmi) grids. The survey area encompassed an area of 858,941 km², of which 26.2 km² was

Table 1.--Survey area (square kilometers) and sampling density for marine debris during the NMFS bottom trawl survey off Oregon, in the eastern Bering Sea, and in Norton Sound, 1988.

	Effort					
Area	Area encompassed by survey (km^2)	Area covered by trawls (km^2)	Percent area sampled	Total number of hauls	Number of hauls with debris	Percent hauls with debris
Oregon	7,230	2.7	0.037%	70	49	70%
Eastern Bering Sea	858,941	26.2	0.003%	541	122	23%
Norton Sound	41,680	4.2	0.010%	85	6	7%
Total	907,851	33.1	0.004%	696	177	25%

actually covered by trawl hauls. Because of differences in sampling density, the eastern Bering Sea survey area was divided into four subareas. The four subareas for analysis were the north-south shelf and slope (Fig. 2).

Eighty-five hauls were conducted in Norton Sound between the 7 and 20 m isobaths (Fig. 2). The Norton Sound survey area encompassed 41,680 km^2 and a total of 4.2 km^2 was actually surveyed.

Trawls were towed on the bottom for approximately 0.5 h at each station at a towing speed of about 5.6 km/h (3 kn). For each haul, location, depth, and distance fished were recorded. The effective path width of the trawl net on the bottom was estimated using a sonar measuring device on a subset of hauls during each survey.

Catches of 1 metric ton or less were entirely sampled. Larger catches were weighed and subsampled, and numbers of marine debris items extrapolated to the total catch. Marine debris items in the catch or subsample were sorted by type of material: plastics, glass, rubber, metal, wood, paper, cloth, and other. Debris items were also described as accurately as possible, such as "plastic strapping band" or "metal beverage can." The number of each of the items caught was recorded on a tally sheet and the vessel, cruise, and haul number indicated. When possible, the U.S. or foreign original of an item was indicated and the percent of all items from U.S., foreign, and unknown sources indicated on each haul tally sheet. The number of entangled animals was recorded by species and debris item. A complete description of NMFS sampling procedures is provided by Wakabayashi et al. (1985).

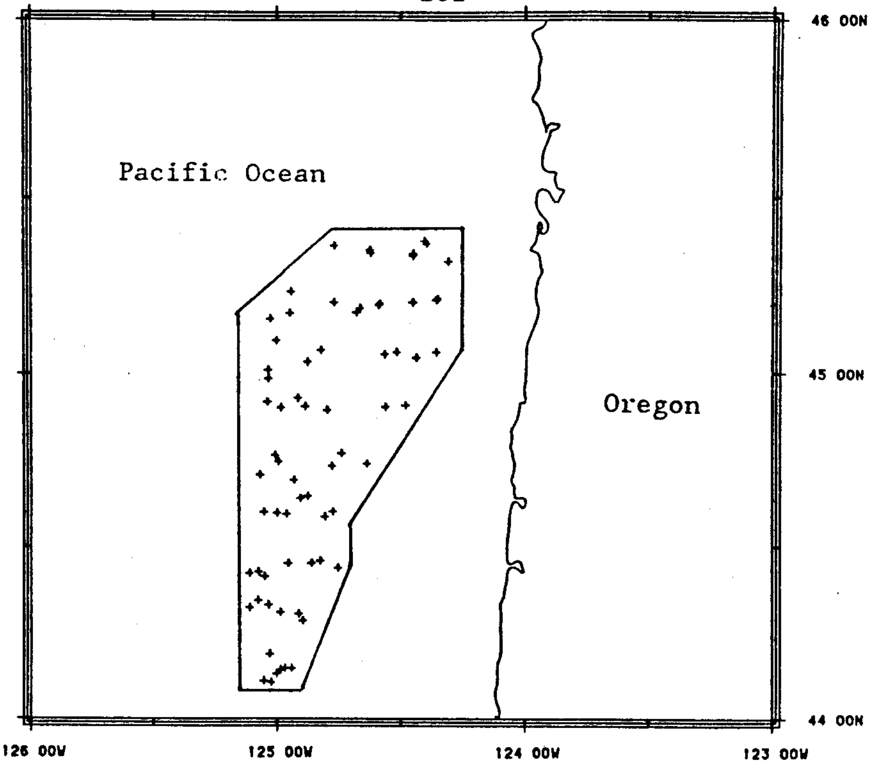

Figure 1.--Area surveyed and station locations sampled for marine debris during the National Marine Fisheries Service bottom trawl survey off Oregon, 1988.

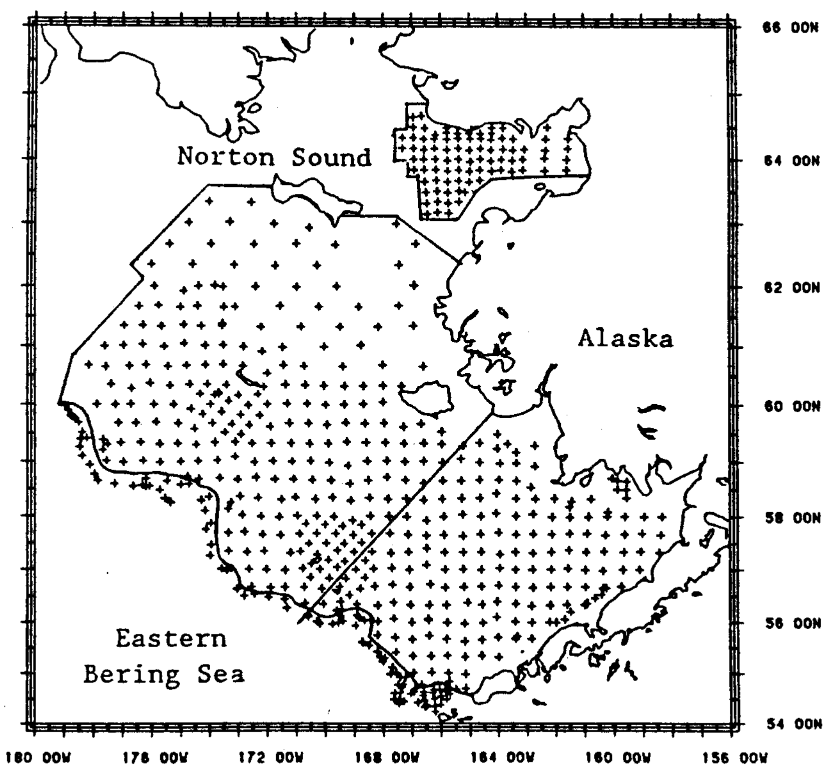

Figure 2.--Area surveyed and station locations sampled for marine debris during the National Marine Fisheries Service bottom trawl survey in the eastern Bering Sea and Norton Sound, 1988.

Vessels and Fishing Gear

The survey off the coast of Oregon was conducted aboard the 64.6 m NOAA ship *Miller Freeman* using two nets, a modified Nor'eastern trawl and a poly-Nor'eastern trawl. The mean effective path width of the poly-Nor'eastern trawl was estimated to be 14.7 m and the modified Nor'eastern 16.4 m. The eastern Bering Sea survey was conducted using three vessels: the *Miller Freeman*, the 30.5 m RV *Alaska*, and the 37.5 m MV *Morning Star*. Two nets were used during the survey, the eastern trawl, with an estimated mean effective path width of 17.0 m, and the modified Nor'eastern trawl used on the Oregon survey. The *Miller Freeman* conducted the Norton Sound survey with the eastern trawl used in the eastern Bering Sea survey. The eastern trawl had 10.2 cm (4 in) mesh in the wings and body, 8.9 cm (3.5 in) mesh in the cod end, and a 3.2 cm (1.25 in) cod end liner. The modified and poly-Nor'eastern had construction similar to the eastern trawl except for 12.7 cm (5 in) mesh in the wings and body.

Data Analysis

It was assumed all debris 6.5 cm^2 (1 in^2) and larger lying on the surface of the bottom and within the mean effective path width of each net was caught with equal efficiency by each net. This assumption may not necessarily be valid for all hauls, since different nets and different towing conditions can affect the ability of the net to catch objects on the bottom. However, since the NMFS has standardized fishing gear and methods used during most of its annual resource assessment surveys, results obtained from the 1988 surveys should be comparable to future surveys using the same gear and techniques. A second assumption was that scientists identified all of the marine debris caught in each haul.

Marine debris items were grouped by use and by material of composition. Use categories included galley waste, personal use waste (e.g., deodorant tubes, gloves, lighters), fishing gear, engineering and fish processing waste, and other unidentified use waste. Material categories included plastic, glass, rubber, metal, wood, paper, and other. Numbers of items caught were summed by use and material categories by haul and by combinations of the two categories, such as plastic galley waste or metal engineering and processing waste.

The effort expended in each haul was calculated in square kilometers by multiplying the distance fished in each haul by the effective path width of the net. The numbers of individual and grouped marine debris items caught in each haul were divided by the effort to give catch-per-unit-effort (CPUE) in numbers of items per square kilometer for each haul. Mean CPUE per haul was calculated for the entire survey area off Oregon and in Norton Sound and for individual subareas in the eastern Bering Sea using the following formulas:

For an individual haul, CPUE = catch in numbers per unit effort in square kilometers.

For the entire survey area,

$$\text{Mean CPUE} = \frac{\Sigma(\text{CPUE})}{N}$$

$$\text{Variance} = \frac{\Sigma((\text{CPUE - mean CPUE})^2)}{(N * (N-1))}$$

where Σ = summation for all hauls in the area,

N = the number of hauls in the area.

In the eastern Bering Sea the mean CPUE and variance for the combined subareas were weighted by the area of each subarea in square kilometers using the formulas:

$$\text{Overall mean CPUE} = \frac{\Sigma(A * \text{mean CPUE})}{\Sigma(A)}$$

$$\text{Variance} = \frac{\Sigma(A^2 * \text{variance (mean CPUE)})}{\Sigma(A)^2}$$

where Σ = summation for all subareas,

A = subarea weighting factor.

South shelf = 299,115 km^2
North shelf = 520,618 km^2
South slope = 17,544 km^2
North slope = 21,660 km^2

Estimates of CPUE for material and use categories and for total debris items were calculated independently and therefore sums of individual categories do not necessarily equal totals. A more complete description of the standard NMFS methods of calculating CPUE is given in Wakabayashi et al. (1985).

Estimates of the total number of items of debris on the bottom of each area during the 1988 surveys were calculated using an area-swept method (Wakabayashi et al. 1985). Mean CPUE and estimates of numbers of items present in each area are presented as baseline estimates for subsequent comparisons within areas and for all areas combined and were not meant to provide statistically significant comparisons between areas. The percent of debris items by use and material categories is presented for each area and for all areas combined.

RESULTS

Oregon

Of the three areas surveyed, the area off Oregon had the highest concentration of marine debris with 149.6 items/km^2 (Table 2, Fig. 3). A total of 399 debris items were caught in 49 out of the 70 hauls completed (Table 1). Within use categories, the mean CPUE of galley waste was 89.4 items/km^2, accounting for 64% of the CPUE of all debris items caught, followed by engineering and processing waste (27%), personal use waste (6%), other use waste (2%), and fishing equipment (1%). Of material categories, the mean CPUE of metal debris was 54.08 items/km^2 and represented 36% of the mean CPUE of all debris caught, followed by plastics (26%) (Fig. 4), glass (19%), rubber (8%), cloth (6%), wood (3%), and paper (1%) (Table 3).

Of the 399 debris items caught off Oregon, 149 or 37% were identified as of either U.S. or foreign origin. Debris of U.S. origin made up 88% of the mean CPUE of debris of identifiable national origin caught off Oregon, 100% of the CPUE for engineering and processing waste and fishing equipment (Table 4). Foreign debris was represented in the CPUE as galley waste (15%) and personal use items (11%). By material category, U.S. debris caught off Oregon dominated all categories except rubber debris, where foreign debris was 54% of the CPUE of identified items (Table 5).

No animals entangled in marine debris were found in the survey off Oregon. Anemones were attached to a glass bottle and starfish were observed on a piece of plastic rope.

Eastern Bering Sea

The mean CPUE of all debris items caught in the eastern Bering Sea was 7.52 items/km^2 (Table 2, Fig. 5). Out of the 541 hauls completed, 122 hauls contained a total of 255 marine debris items (Table 1). Galley waste CPUE was 3.15 items/km^2 or 40% of the mean total CPUE, followed by fishing equipment (24%), engineering and processing waste (24%), and personal use waste (12%). By material category, plastic dominated the total mean CPUE with 4.4 items/km^2 (51%) (Fig. 6), followed by metal debris (27%), rubber debris (9%), cloth debris (5%), glass debris (4%), and wood debris (1%) (Table 3).

Of the 255 debris items caught in the eastern Bering Sea, U.S. or foreign origin was identified for 60 items. Foreign debris dominated the identified items, accounting for 70% of the mean CPUE (Table 4). Foreign debris was 76% of the CPUE of identified galley waste and 93% of the personal use waste CPUE. Debris of U.S. origin was greatest in fishing equipment waste (67% of CPUE) and engineering and processing waste (64% of CPUE). Foreign debris made up most of the plastic (76% of CPUE), metal (57% of CPUE), rubber (100% of CPUE), and glass debris (84% of CPUE) (Table 5). The U.S. debris accounted for 100% of the CPUE of identified paper and other material debris.

Table 2.--Catch-per-unit-effort (CPUE) (number per square kilometer) by use category and area for marine debris caught during the National Marine Fisheries Service bottom trawl survey, 1988 (CI = confidence interval).

Use category	Oregon		Eastern Bering Sea		Norton Sound		All areas	
	Number/km^2 (95% CI N = 70)	Percent of area total CPUE	Number/km^2 (95% CI N = 70)	Percent of area total CPUE	Number/km^2 (95% CI N = 70)	Percent of area total CPUE	Number/km^2 (95% CI N = 70)	Percent of area total CPUE
Galley wastes	89.40 (57.2-121.6)	64%	3.15 (2.1-7.2)	40%	0.70 (0.0-1.7)	36%	5.12 (2.7-7.6)	51%
Engineering and processing	37.87 (18.3-57.4)	27%	1.84 (1.0-2.6)	23%	0.73 (0.0-1.8)	38%	2.10 (1.3-2.8)	21%
Fishing equipmment	1.69 (0.0-3.4)	1%	1.86 (1.1-2.6)	24%	0.00 --	0%	1.80 (1.1-2.5)	18%
Personal use items	8.92 (0-18.9)	6%	0.91 (0.0-1.9)	12%	0.51 (0.0-1.2)	26%	0.96 (0.0-1.9)	10%
Other debris	2.55 (0.0-6.6)	2%	0.08 (0.0-0.2)	1%	0.00 --	0%	0.05 (0.0-0.1)	<1%
Total	149.60 (97.9-201.3)	100%	7.52 (6.7-14.4)	100%	1.94 (0.3-3.6)	100%	11.26 (7.6-14.9)	100%

Note: Individual and total debris categories were calculated separately and thus are not necessarily additive.

Table 3.--Catch-per-unit-effort (CPUE) (number per square kilometer) by debris material category and area for marine debris caught during the National Marine Fisheries Service bottom trawl survey, 1988 (CI = confidence interval).

Debris category	Oregon		Eastern Bering Sea		Norton Sound		All areas	
	Number/km^2 (95% CI N = 70)	Percent of area total CPUE	Number/km^2 (95% CI N = 70)	Percent of area total CPUE	Number/km^2 (95% CI N = 70)	Percent of area total CPUE	Number/km^2 (95% CI N = 70)	Percent of area total CPUE
Plastic	39.05 (20.7-57.4)	26%	4.40 (4.9-7.8)	51%	0.24 (0.0-0.7)	12%	6.37 (5.0-7.7)	57%
Metal	54.08 (29.6-78.6)	36%	2.33 (0.0-4.8)	27%	0.96 (0.0-2.3)	49%	2.68 (0.3-5.0)	24%
Rubber	12.10 (0.3-23.9)	8%	0.80 (0.0-1.8)	9%	0.26 (0.0-0.8)	13%	0.87 (0.0-1.8)	8%
Glass	28.66 (16.4-40.9)	19%	0.38 (0.1-0.6)	4%	0.00 --	0%	0.59 (0.3-0.8)	5%
Cloth	9.61 (3.6-15.6)	6%	0.41 (0.1-0.7)	5%	0.48 (0.0-1.2)	25%	0.49 (0.2-0.8)	4%
Wood	4.24 (0.0-8.9)	3%	0.11 (0.0-0.2)	1%	0.00 --	0%	0.14 (0.0-0.3)	1%
Paper	1.34 (0.0-2.7)	1%	0.13 (0.0-0.3)	2%	0.00 --	0%	0.13 (0.0-0.3)	1%
Other	0.54 (0.0-6.4)	<1%	0.00 --	0%	0.00 --	0%	>0.01 (0.0-0.1)	<1%
Total	149.60 (97.9-201.3)	100%	7.52 (6.7-14.4)	100%	1.94 (0.3-3.6)	100%	11.26 (7.6-14.9)	100%

Note: Individual and total debris categories were calculated separately and thus are not necessarily additive.

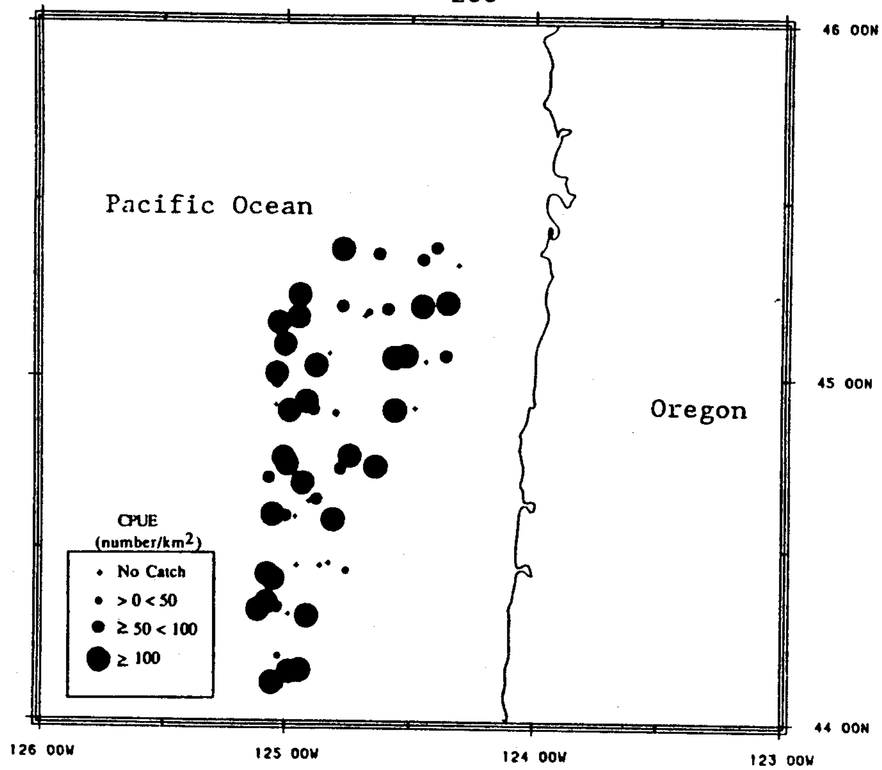

Figure 3.--Relative density (catch-per-unit-effort (CPUE) in number per square kilometer) of all marine debris caught during the National Marine Fisheries Service bottom trawl survey off Oregon, 1988.

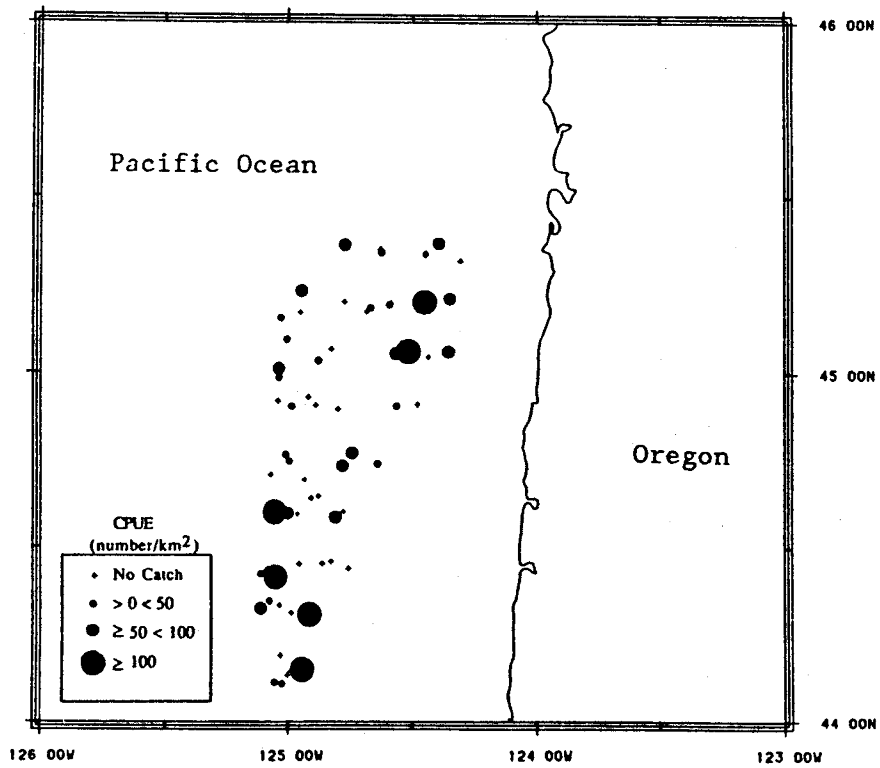

Figure 4.--Relative density (catch-per-unit-effort (CPUE) in number per square kilometer) of plastic marine debris caught during the National Marine Fisheries Service bottom trawl survey off Oregon, 1988.

Table 4.--Percent of catch-per-unit-effort (number per square kilometer) by foreign or domestic (U.S.) origin, use category, and area for marine debris caught during the National Marine Fisheries Service bottom trawl survey, 1988.

	Oregon		Eastern Bering Sea		Norton Sound		All areas	
Use category	U.S.	Foreign	U.S.	Foreign	U.S.	Foreign	U.S.	Foreign
Galley wastes	85%	15%	24%	76%	0%	0%	37%	63%
Engineering and processing	100%	0%	64%	36%	100%	0%	75%	25%
Fishing equipment	100%	0%	67%	33%	0%	0%	66%	34%
Personal use items	89%	11%	7%	93%	0%	0%	24%	76%
Other debris	100%	0%	100%	0%	0%	0%	100%	0%
Percent by area	88%	12%	30%	70%	100%	0%	42%	58%

Table 5.--Percent of catch-per-unit-effort (number per square kilometer) by foreign or domestic (U.S.) origin, material category, and area for marine debris caught during the National Marine Fisheries Service bottom trawl survey, 1988.

	Oregon		Eastern Bering Sea		Norton Sound		All areas	
Debris material	U.S.	Foreign	U.S.	Foreign	U.S.	Foreign	U.S.	Foreign
Plastic	100%	0%	24%	76%	0%	0%	33%	67%
Metal	85%	15%	43%	57%	100%	0%	55%	45%
Rubber	46%	54%	0%	100%	0%	0%	4%	96%
Glass	81%	19%	16%	84%	0%	0%	37%	63%
Cloth	0%	0%	0%	0%	0%	0%	0%	0%
Wood	100%	0%	0%	0%	0%	0%	100%	0%
Paper	100%	0%	100%	0%	0%	0%	100%	0%
Other	100%	0%	100%	0%	0%	0%	100%	0%
Percent by area	88%	12%	30%	70%	100%	0%	43%	57%

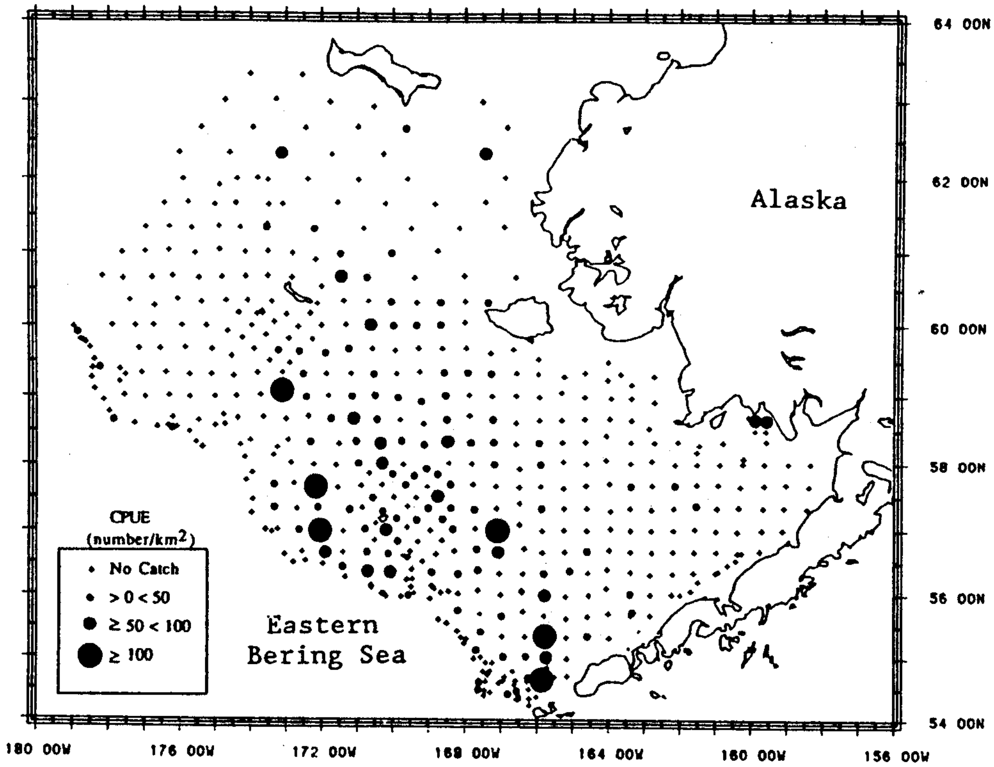

Figure 5.--Relative density (catch-per-unit-effort (CPUE) in number per square kilometer) of all marine debris caught during the National Marine Fisheries Service bottom trawl survey in the eastern Bering Sea, 1988.

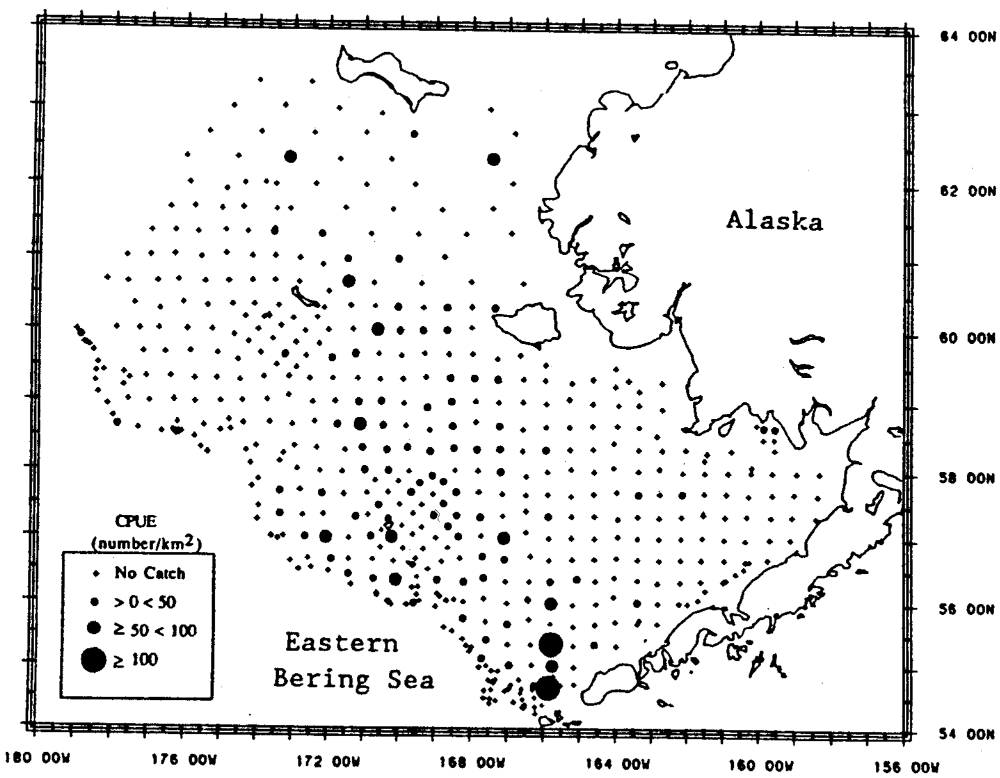

Figure 6.--Relative density (catch-per-unit-effort (CPUE) in number per square kilometer) of plastic marine debris caught during the National Marine Fisheries Service bottom trawl survey in the eastern Bering Sea, 1988.

A Tanner crab, *Chionoecetes opilio*, and an unidentified hermit crab, Paguridae, entangled in separate pieces of plastic trawl web twine, were caught during the eastern Bering Sea survey. Numerous invertebrates including mussels, anemones, octopus, barnacles, unidentified tunicates, and starfish were associated with plastic sheeting, plastic rope, glass bottles, and a rubber shoe. Fish eggs were found attached to plastic sheeting.

Norton Sound

Of the three areas surveyed, Norton Sound had the lowest concentration of marine debris, with 1.94 items/km^2 (Table 2, Fig. 7). Eight items of debris were found in 6 of the 85 hauls completed. Galley waste had a mean CPUE of 0.73 items/km^2 or 38% of the total debris mean CPUE followed by engineering and processing waste (36%), and personal use waste (26%). No fishing equipment waste was found in Norton Sound. Metal debris accounted for 49% of the total debris mean CPUE, cloth debris 25%, rubber debris 13%, and plastic debris 12% of the total debris mean CPUE (Fig. 8).

Out of the eight debris items caught in Norton Sound, a single debris item, a metal piece of railroad track, was identified as being of U.S. origin.

No animals were found entangled or associated with marine debris in Norton Sound.

All Areas Combined

Out of a total of 696 trawl hauls examined for marine debris in the 3 areas, 177 (25%) had a total of 662 marine debris items identified in the catch. For the 3 areas combined, the mean CPUE of all debris items, weighted by surface area, was 11.3 items/km^2 (Table 2). Galley waste accounted for 51% of the mean CPUE of all debris items, followed by engineering and processing waste (21%), fishing equipment waste (18%), and personal use waste (10%). Over all areas surveyed, plastic was the most abundant debris material, caught with a mean CPUE of 6.37 items/km^2 (57% of the mean total CPUE), followed by metal debris (24%), rubber (8%), glass (5%), cloth (4%), and wood and paper (1% of the mean total CPUE) (Table 3).

Of the 210 debris items identified to national origin in the 3 areas, 58% of the mean total CPUE was foreign (Table 4). Foreign debris dominated galley waste (63%) and personal use waste (76%). The U.S. debris accounted for 75% of the mean CPUE of identified engineering and processing waste and 66% of identified fishing equipment waste mean CPUE. Foreign debris accounted for 67% of the mean CPUE of identified plastic debris, 96% of rubber debris, and 63% of the mean CPUE of identified glass debris (Table 5). The U.S. debris dominated identified debris made of metal (55% of mean CPUE) and accounted for all of the identified wood and paper debris caught in the three areas. Plastic represented the largest percentage of CPUE of galley waste (46%), engineering and processing waste (48%), and fishing equipment waste (92%) (Table 6). Rubber debris made up most of the CPUE of personal use waste (77%). A complete list of the individual marine debris items found during the survey is found in Tables 7 through 9.

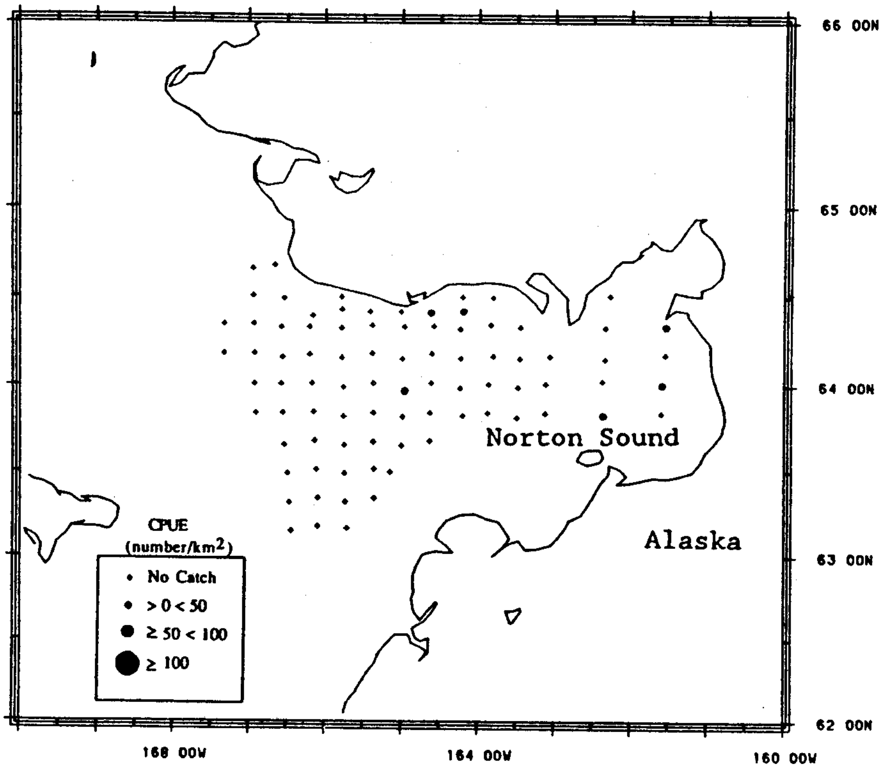

Figure 7.--Relative density (catch-per-unit-effort (CPUE) in number per square kilometer) of plastic marine debris caught during the National Marine Fisheries Service bottom trawl survey in the Norton Sound, 1988.

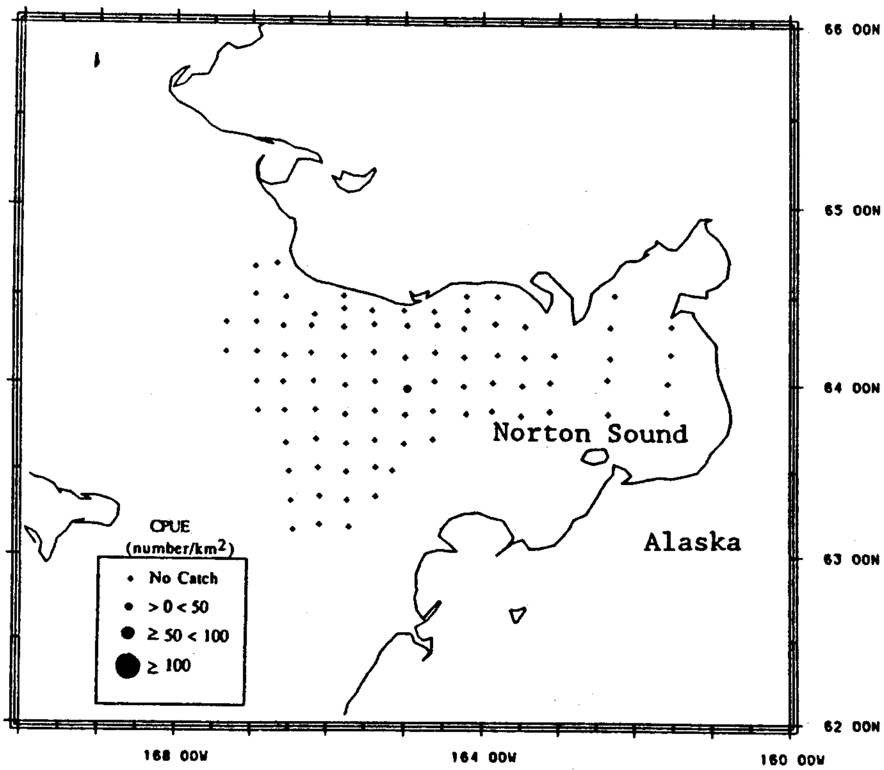

Figure 8.--Relative density (catch-per-unit-effort (CPUE) in number per square kilometer) of all marine debris caught during the National Marine Fisheries Service bottom trawl survey in the Norton Sound, 1988.

Table 6.--Percent of catch-per-unit-effort (number per square kilometer) by debris material and use categories for marine debris caught during the National Marine Fisheries Service bottom trawl survey off Oregon, in the eastern Bering Sea, and in Norton Sound, 1988.

	Use category					
Debris	Galley wastes	Engineering and processing	Fishing equipment	Personal use	Other	Percent by material category
Plastic	45.8%	47.5%	91.8%	9.9%	65.4%	56.6%
Metal	42.9%	16.9%	6.1%	0.0%	30.8%	23.8%
Rubber	0.0%	6.1%	0.0%	77.4%	3.8%	7.7%
Glass	10.7%	0.0%	2.1%	0.0%	0.0%	5.2%
Cloth	0.0%	20.3%	0.0%	7.0%	0.0%	4.3%
Wood	0.0%	6.5%	0.0%	0.0%	0.0%	1.2%
Paper	0.5%	2.5%	0.0%	5.6%	0.0%	1.2%
Other	0.0%	0.2%	0.0%	0.0%	0.0%	<1%
Percent by use category	51.3%	20.8%	17.8%	9.6%	0.5%	100.0%

DISCUSSION

The three areas surveyed provide an interesting comparison of the abundance and type of marine debris found on the bottom in areas with different amounts and types of vessel use. The area off Oregon is used extensively by cargo vessels, U.S. and U.S.-foreign joint venture commercial fishing operations, and recreational boaters and fishermen. In 1985, the latest year for which data are available, approximately 1,740 commercial fishing vessels operated off the coast of Oregon (Korson and Thomson 1987) and the U.S. Coast Guard reported 143,373 commercial and recreational vessels in Oregon with Coast Guard identification numbers (Coast Guard 1986). The area surveyed off Oregon is located on one of the major north-south west coast cargo shipping lanes, with frequent vessel traffic observed during the survey (T. Dark, Alaska Fisheries Science Center, Seattle, Wash., pers. commun. 1989).

In the eastern Bering Sea, some nonfishery tug, barge, and cargo vessel operations exist, but vessel traffic is predominantly associated with the commercial fishing industry. Harvesting vessels, domestic and foreign processing vessels, and a wide variety of support vessels operate in the eastern Bering Sea each year. In 1985, the Alaska Department of Fish and Game (1986) estimated that 1,729 domestic commercial fishing vessels operated in the eastern Bering Sea, and the NMFS estimated that 254 254 foreign vessels fished or processed seafood in the eastern Bering

Table 7.--Description, material and use category, number caught, catch-per-unit-effort (CPUE) (number per square kilometer), and swept-area estimate of the number of debris items in the survey area for marine debris caught off Oregon during the National Marine Fisheries Service bottom trawl survey, 1988 (CI - confidence interval).

		Catch			Swept-area estimate	
Use category	Item	Number caught	Mean CPUE km^2	CPUE variance	Estimated number	95% CI
			Plastic			
Galley waste	Bags	39	14.31	11.2468	103,277	54,946-151,607
	Bottles	2	0.51	0.1290	3,702	0-8,896
	Lids, caps	4	1.71	1.4426	12,325	0-29,634
	Six-pack ring	1	0.25	0.0624	1,803	0-5,405
	Vegetable sack	1	0.90	0.8185	6,529	0-19,567
	Other	2	0.72	0.2909	5,170	0-12,943
Fishing equipment	Fishing line	2	0.88	0.4228	6,347	0-15,718
	Fishing net	1	0.27	0.0732	1,952	0-5,850
	Rope	21	9.45	12.9024	68,218	0-119,983
Personal use	Lighter	1	0.27	0.0717	1,932	0-5,790
	Deodorant tube	15	4.02	16.1272	28,981	0-86,855
Engineering and processing	Sheeting	8	2.36	2.8377	17,058	0-41,339
	Strapping band	9	2.92	1.2100	21,102	0-36,955
	Duct tape	1	0.22	0.0494	1,605	0-4,809
Other	Clay pigeon	1	0.25	0.0601	1,770	0-5,303
			Glass			
Galley waste	Bottle	65	25.92	32.4534	187,265	105,167-269,364
	Pieces	2	0.75	0.3088	5,447	0-13,456
	Fruit jar	4	1.95	3.0305	14,082	0-39,170
			Rubber			
Personal use	Gloves	6	2.47	0.1049	17,798	3,035-32,561
	Shoe	1	0.86	0.4123	6,211	0-15,465
Engineering and processing	Tar	10	5.05	0.2546	36,411	0-109,125
	Gasket	3	0.79	0.3292	5,666	0-13,935
	Paint	4	1.80	2.4378	13,012	0-35,513
	Sheeting	2	0.87	0.4358	6,287	0-15,801
Other	Misc. pieces	1	0.27	0.0702	1,913	0-5,732

Table 7.--Continued.

Use category	Item	Catch: Number caught	Catch: Mean CPUE km²	Catch: CPUE variance	Swept-area estimate: Estimated number	Swept-area estimate: 95% CI
			Metal			
Galley waste	Beverage can	95	35.38	75.5465	255,327	130,066-380,587
	Lids, caps	4	1.46	0.8108	10,537	0-23,514
	Container	5	1.96	0.8102	14,136	1,164-27,108
	Pull tab	7	2.50	3.1064	18,075	0-43,475
	Tinfoil	2	0.50	0.1231	3,581	0-8,638
	Cook pot	2	0.54	0.1429	3,879	0-9,326
Fishing equipment	Crab trap	1	0.54	0.2867	4	0-11,581
Engineering and processing	Drum, 208.2 liter (55-gal)	1	0.50	0.2546	3,641	0-10,913
	Pieces	16	5.94	7.1185	42,849	4,398-81,299
	Instruments	3	0.97	0.3255	6,972	0-15,193
	Paint can	4	1.76	2.4200	12,715	0-35,134
Other	Bullet	4	2.04	4.1527	14,706	0-44,074
			Paper			
Personal use	Newspaper	1	0.27	0.0717	1,932	0-5,709
	Pieces	2	0.53	0.1371	3,807	0-9,144
	Book	1	0.25	0.0613	1,770	0-5,303
Engineering and processing	Carton	1	0.30	0.0879	2,139	0-6,412
			Wood			
Engineering an processing	Pieces	14	3.76	5.2919	26,951	0-60,103
	Broom	1	0.29	0.0813	2,058	0-6,168
	Fiberboard	1	0.22	0.0494	1,605	0-4,809
			Cloth			
Engineering and processing	Pieces and rags	6	9.61	9.0228	69,330	26,041-112,619
			Other			
Engineering and processing	Fire brick	26	0.54	0.2867	3,864	0-11,581

Table 8.--Description, material and use category, number caught, catch-per-unit-effort (CPUE) (number per square kilometer), and swept-area estimate of the number of debris items in the survey area in the eastern Bering Sea during the National Marine Fisheries Service bottom trawl survey, 1988 (CI = confidence interval).

		Catch			Swept-area estimate	
Use category	Item	Number caught	Mean CPUE km^2	CPUE variance	Estimated number	95% CI
		Plastic				
Galley waste	Bags	49	1.10	0.0653	1,629,941	1,195,289-2,064,593
	Bottles	2	0.01	0.0017	11,209	0-33,626
	Lids, caps	3	0.11	0.0070	97,164	0-239,880
	Wrappers	4	0.21	0.0177	177,959	0-404,079
	Other	1	0.04	0.0016	34,424	0-102,581
Fishing equipment	Bait jar	2	0.09	0.0041	74,915	0-183,768
	Fishing line	17	0.78	0.0546	669,889	272,412-1,067,367
	Fishing net	7	0.35	0.0173	299,166	75,558-522,774
	Net twine	8	0.33	0.0140	285,103	83,872-486,335
	Floats	1	0.05	0.0030	46,871	0-139,671
	Light stick	2	0.11	0.0113	91,208	0-271,792
	Rope	28	1.32	0.0646	1,131,965	669,668-1,564,263
Personal use	Hard hat	1	0.01	0.0001	5,894	0-17,681
	Toothpaste tube	2	0.05	0.0017	40,270	0-109,798
	Glove liner	1	0.01	0.0001	9,100	0-27,491
Engineering and processing	Sheeting	15	0.72	0.0775	619,684	146,206-1,093,162
	Strapping band	7	0.22	0.0094	192,401	27,813-356,990
	Duct tape	1	0.05	0.0026	44,114	0-131,455
Other	Clay pigeon	1	0.04	0.0017	35,414	0-105,532
	XBT tube[a]	1	0.04	0.0013	30,766	0-91,681
		Glass				
Galley waste	Bottle	8	0.31	0.0133	263,374	67,448-459,299
	Pieces	1	0.03	0.0010	28,129	0-83,823
Fishing equipment	Glass float	1	0.04	0.0016	34,424	0-102,581
		Rubber				
Personal use	Gloves	14	0.67	0.2437	571,566	0-1,411,060
	Shoes	2	0.07	0.0028	64,347	0-154,201
Engineering and processing	Tar	1	0.01	0.0001	6,433	0-19,299
	Sheeting	1	0.05	0.0030	47,198	0-140,648

Table 8.--Continued.

Use category	Item	Catch: Number caught	Catch: Mean CPUE km²	Catch: CPUE variance	Swept-area estimate: Estimated number	Swept-area estimate: 95% CI
			Metal			
Galley waste	Beverage can	33	1.55	1.4860	1,328,689	0-3,401,783
	Lids, caps	1	0.05	0.0029	45,914	0-136,821
	Container	7	0.26	0.0188	223,756	0-457,004
	Tinfoil	1	0.05	0.0026	43,827	0-130,601
	Cook pot	1	0.03	0.0012	29,301	0-87,316
Fishing equipment	Crab trap	3	0.11	0.0050	94,090	0-214,290
Engineering and processing	Pieces	3	0.17	0.0280	143,604	0-427,928
	Wire	9	0.10	0.0054	89,238	0-214,176
			Paper			
Galley waste	Bag	1	0.03	0.0008	24,249	0-72,261
Personal use	Piece	1	0.05	0.0024	41,663	0-124,152
Engineering and processing	Carton	1	0.05	0.0027	44,404	0-132,320
			Wood			
Engineering and processing	Pieces	2	0.04	0.0014	37,988	0-101,750
	Paint brush	1	0.03	0.0010	27,047	0-80,599
	Other	1	0.03	0.0010	27,196	0-81,044
			Cloth			
Personal use	Pants	1	0.06	0.0034	49,995	0-148,982
Engineering and processing	Pieces	6	0.25	0.0120	217,809	31,675-403,944
	Tarp	1	0.05	0.0026	43,544	0-129,759
	Bag	1	0.05	0.0024	41,663	0-124,152

[a]XBT - Expendable bathythermograph.

Table 9.--Description, material and use category, number caught, catch-per-unit-effort (CPUE) (number per square kilometer), and swept-area estimate of the number of debris items in the survey area for marine debris caught in Norton Sound during the National Marine Fisheries Service bottom trawl survey, 1988 (CI = confidence interval).

Category			Catch			Swept-area estimate	
Material	Use	Item	Number caught	Mean CPUE No./km^2	CPUE variance	Estimated number	95% CI
Plastic	Galley waste	Bag	1	0.24	0.0559	9,857	0-29,493
Rubber	Personal use	Shoe	1	0.26	0.0664	10,741	0-32,138
Metal	Galley waste	Beverage can	2	0.46	0.2128	19,228	0-57,530
	Engineering and processing	Railroad track	2	0.50	0.2516	20,906	0-62,557
Cloth	Engineering and processing	Pieces and rags	1	0.23	0.0539	9,674	0-28,947
	Personal use	Dress	1	0.25	0.0629	10,453	0-31,275

Sea-Aleutian Islands area (Berger et al. 1988). There are few, if any, recreational boaters operating in the eastern Bering Sea and the major cargo transit routes lie south of the Aleutian Islands.

Norton Sound has the least amount of vessel traffic of the three areas surveyed. Tug and barge traffic to Nome, Alaska, occurs during the spring and summer. A fleet of about a dozen vessels conducts a commercial red king crab fishery in the survey area for approximately 1 week each year (Alaska Department of Fish and Game 1986). During the winter, most of Norton Sound is covered by ice.

The estimated abundance of marine debris in the three areas surveyed differed by nearly two orders of magnitude, from 1.94 items/km^2 in Norton Sound to 149.60 items/km^2 off Oregon. The higher concentration of marine debris off Oregon is probably related to the extensive vessel operations in this area. Most of the marine debris off Oregon was galley waste, 89.4 items/km^2 (64%), and engineering and processing waste, 37.87 items/km^2 (27%), which are associated with the operation of most types of vessels. Fishing equipment waste abundance off Oregon, 1.69 items/km^2, was quite similar to that found in the eastern Bering Sea, 1.84 items/km^2. It is interesting to note that the numbers of commercial fishing vessels operating off Oregon and in the eastern Bering Sea were also similar, 1,740 and 1,983, respectively. The abundance of galley waste and engineering and processing debris caught in the eastern Bering Sea may represent the average amount resulting from commercial fishing operations and minimal cargo traffic. The higher abundance of galley waste and engineering and processing waste found off Oregon may be due to the added input of cargo vessel and recreational boater debris.

RECOMMENDATIONS

- Collect marine debris data from all annual NMFS bottom trawl surveys.
- Develop a standardized data collection protocol, data base system, analysis methodology, and reporting format.
- Provide similar marine debris data forms to commercial trawl fishermen.
- Encourage foreign governments to conduct similar bottom trawl marine debris surveys.

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ESTIMATING THE DENSITY OF FLOATING MARINE DEBRIS: DESIGN CONSIDERATIONS

Christine A. Ribic* and L. J. Bledsoe
Center for Quantitative Science in Forestry, Fisheries, and Wildlife
University of Washington
Seattle, Washington 98195, U.S.A.

*Present address: Environmental Research Laboratory, U.S. Environmental Protection Agency, 200 SW 35th Street, Corvallis, OR 97333, U.S.A.

ABSTRACT

We calculated sample sizes needed to estimate the density of surface marine debris potentially injurious to marine mammal and bird populations in the Gulf of Alaska and the Bering Sea as well as sample sizes needed to specifically estimate floating nets. Using published estimates of debris density, we developed alternative sample size requirements that depended on the accuracy required based on the coefficient of variation of the density. The survey technique used was visual sighting of debris using strip transect methodology. In general, large numbers of transects are needed in order to get estimates even with large coefficients of variation. Sparsity of data and nonstandard definition of transects contribute to the problems in estimating required sample sizes.

INTRODUCTION

The problems of marine debris and its impacts on marine mammals and on human activity in the oceans have been reviewed and discussed extensively by Shomura and Yoshida (1985). There has been interest in estimating the amount of floating marine debris using visual assessment. This technique has been used by many researchers (Venrick et al. 1973; Suzuoki and Shirakawa 1979; Dahlberg and Day 1985; Jones and Ferrero 1985; Yoshida and Baba 1985a, 1985b, 1988; Baba et al. 1986; Ignell and Dahlberg 1986; Day and Shaw 1987; McCoy 1988; Mio and Takehama 1988; Yagi and Nomura 1988). The purpose of this paper is to investigate survey design to estimate the density of surface marine debris in the Gulf of Alaska and Bering Sea.

We considered the design of two surveys. The first was to estimate density for all potentially harmful floating debris that could be visually assessed (specifically nets, fragmented plastic pieces, and strapping bands). Each type of debris was assumed to be equally important. The second design was for estimating the density of floating nets only.

In R. S. Shomura and M. L. Godfrey (editors), Proceedings of the Second International Conference on Marine Debris, 2-7 April 1989, Honolulu, Hawaii. U.S. Dep. Commer., NOAA Tech. Memo. NMFS, NOAA-TM-NMFS-SWFSC-154. 1990.

METHODS

The strip transect was the method used for visually assessing the density of floating objects. This method was chosen because of its widespread use (references cited above). The transects have a fixed width and the assumption is that all objects within that width are seen. The method of Burnham et al. (1980) was used to estimate sample size. This method is nonparametric because it does not make an assumption about the distribution of the debris. Estimation of sample size is based on achieving a certain coefficient of variation for the density of objects.

We used the conservative estimate for total transect length:

$$L = (3 \cdot L1)/(cv(D)^2 \cdot n1)$$

where L1 (total length of transects) and n1 (total number of objects seen) come from a pilot study, and cv(D) is the coefficient of variation (Burnham et al. 1980).

We used previously published papers on the Gulf of Alaska and the Bering Sea for estimates of L1 and n1 for total floating debris and floating nets. In addition, the data for the 1984 marine mammal observer program were made available to us (L. Jones, National Marine Mammal Laboratory, Seattle, WA, pers. commun.).

RESULTS

Total Floating Debris

From Dahlberg and Day (1985), an estimate of all debris was based on a strip transect with a width of 50 m. They do not state the length of their transects but state that an average of 5.5 h/day were spent watching for debris and that 1,516 nmi were sampled from Alaska to Hawaii (Dahlberg and Day 1985). This gives an average transect length of 47 nmi covered per 5.5 h. So the sampling unit will be defined here as a transect 47 nmi long by 50 m wide. Twelve objects were seen in the Gulf of Alaska (n1) and we estimate 670 nmi (Dahlberg and Day 1985, fig. 3) was surveyed (L1). Dahlberg and Day (1985) gave a density estimate for all floating marine debris as 0.28 pieces/km^2, but they did not publish a variance estimate. Day and Shaw (1987) give density and variance estimates for large floating plastic for the subarctic North Pacific (Gulf of Alaska) and, separately, for the Bering Sea.

Estimates of required sample sizes (number of transects) for estimating total floating debris are presented in Table 1. In general, in order to estimate density to any degree of precision (low cv(D)), 2 months or more of daily transects (5.5 h of observation for a 47-nmi-long by 50-m-wide transect) would be needed. Dahlberg and Day (1985) carried out about 14 transects, which would put their estimate in the 0.50 cv(D) category (not a small coefficient of variation).

Table 1.--Sample size estimation for all floating marine debris using a strip transect of 47 nmi long by 50 m wide for the Gulf of Alaska and the Bering Sea for different coefficients of variation for the density. (L = total transect length and n = number of transects needed to cover that length.)

cv(D)	L (nmi)	n
0.10	16,750	994
0.25	2,680	57
0.50	670	15
0.80	262	6
1.0	167	4
1.2	117	3

Nets

From Jones and Ferrero (1985), 8,759 nmi (L1) were surveyed in 1984 with 12 pieces of net seen (nl). A density estimate of floating nets would be 0.0074 nets/km^2. A transect for this study was 2 nmi in length and 100 m in width. A total of 1,410 transects were made.

Estimates of total sample size (number of transects) for estimating floating nets are presented in Table 2. In all cases, a large number of transects (2 nmi length by 100 m width) would need to be made to get even an inaccurate estimate of the density of nets. There were 1,410 transects made in 1984, which would put the net density estimate in the 0.80 cv(D) category, a large coefficient of variation.

DISCUSSION

The number of transects needed to produce a reasonable estimate for floating marine debris and especially for nets is extremely large. This demonstrates that targeting for a specific type of debris that is relatively rare, like floating nets, will take a large commitment of resources. These sample size estimates, however, depend on a large number of factors.

First, the approach we used is a nonparametric approach that is extremely general and requires sighting 25 or more objects to produce estimates of means and variances with any degree of accuracy (Burnham et al. 1980). Sample sizes for estimating rare objects like floating nets will be extremely large. A parametric approach such as using a binomial distribution may lead to smaller sample sizes but then the underlying model will have to be verified (Ribic and Bledsoe 1986).

Second, there was little information on which to base preliminary estimates of density and variation. Some of this had to do with the way

Table 2.--Sample size estimation for floating nets using a strip transect of 2 nmi long by 100 m wide for the Gulf of Alaska and the Bering Sea for different coefficients of variation for the density. (L = total transect length and n = number of transects needed to cover that length.)

cv(D)	L (nmi)	n
0.10	218,975	109,488
0.25	35,036	17,518
0.50	8,760	4,380
0.80	3,422	1,711
1.0	2,190	1,095
1.2	1,521	761

the data were reported. For example, in some cases we could not determine the length of a transect so we could not use the reported data. But more importantly, there is little published information on which to base preliminary estimates. Dahlberg and Day (1985) worked along long. 155°W. Jones and Ferrero (1985) worked in the middle of the gillnet fishery. Whether these studies are representative of the rest of the unsampled area is not known.

Third, transect length and width are not standardized, so sample size estimates in this paper depend on a specifically defined transect. Density estimates depend on the dimensions of the strip transect. Therefore, generalizations are difficult, since most researchers use different transect widths and lengths for their transects (e.g., Mio and Takehama (1988) used a width of 10 m).

Fourth, due to lack of information on variation for the Gulf of Alaska and the Bering Sea, we did not consider stratification (Cochran 1977), which could be potentially very useful in determining sample allocation and the placement of transect lines. Dahlberg and Day (1985) and Ignell and Dahlberg (1986) noted the concentration of debris in downwelling areas and frontal zones. A large-scale survey such as that of Mio and Takehama (1988) for the Gulf of Alaska and the Bering Sea would greatly improve our knowledge of the distribution of marine debris and improve survey design immensely.

Further refinement of the survey objective would be helpful when we consider placement of the transect lines. If a study is a one-time occurrence, the transects can be considered temporary and location will be decided by where the ship goes. However, if the study is to be a long-term study, thought should be given to permanent transects. For example, Day and Shaw (1987) compared the density of debris along long. 155°W previously sampled by Dahlberg and Day (1985). The long. 155°W line would be an example of a permanent transect that could be surveyed over time. Another example is the study of Yagi and Nomura (1988), where the long. 137°E line was surveyed between lat. 0° and 34°N each summer and winter for 9 years; however, they commented that their limited coverage of the area did not allow them to make conclusions about changes in marine debris distribution over time.

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CHARACTERIZATION OF MARINE DEBRIS IN SELECTED HARBORS OF THE UNITED STATES

Wayne R. Trulli, Heather K. Trulli
Battelle Memorial Institute
397 Washington Street
Duxbury, Massachusetts 02332, U.S.A.

and

David P. Redford
Office of Marine and Estuarine Protection
U.S. Environmental Protection Agency
401 M Street, S.W.
Washington, D.C. 20460, U.S.A.

ABSTRACT

As part of a program to characterize anthropogenic debris in the marine environment, the U.S. Environmental Protection Agency conducted field surveys in the harbors of nine major metropolitan areas of the United States: New York, Boston, Philadelphia, Baltimore, and Miami on the east coast, and Tacoma, Seattle, Oakland, and San Francisco on the west coast. The surveys were designed to provide information on the types, relative amounts, and distributions of marine debris in several geographic regions of the United States. Neuston net (0.3-mm mesh) tows were conducted during outgoing tides on consecutive days. After each net tow, the debris, which ranged in size from small plastic pellets to large plastic sheeting, was identified, categorized, and counted. Seven of the ten most common debris items collected were plastic or polystyrene materials. The data are being used to qualitatively characterize marine debris in coastal metropolitan areas and to examine potential regional variations and sources.

INTRODUCTION

In response to domestic and international concerns about marine plastic debris, the U.S. Congress passed the Marine Plastic Pollution Research and Control Act of 1987. Title II of this act directs the U.S. Environmental Protection Agency (EPA) to conduct a study and to issue a Report to the Congress on methods for reducing plastic pollution. One section of the comprehensive Report to the Congress discusses the types and sources of marine plastic debris, the transport and fate of this debris, and its effects on the marine environment and on human health and safety.

In R. S. Shomura and M. L. Godfrey (editors), Proceedings of the Second International Conference on Marine Debris, 2-7 April 1989, Honolulu, Hawaii. U.S. Dep. Commer., NOAA Tech. Memo. NMFS, NOAA-TM-NMFS-SWFSC-154. 1990.

It also lists what EPA believes to be items of concern in the marine debris. These items are pellets, condoms, tampons, syringes and medical items, nets and traps, line and rope, six-pack yokes (or similar beverage yokes), and plastic bags and sheeting.

Because few data were available prior to the preparation of the Report to the Congress, EPA determined that field studies were necessary to collect data to adequately characterize plastic debris and its sources along the coastal United States. The Harbor Studies Program (Redford 1990), initiated by EPA in 1988, focuses on examining plastic and other floating debris in major harbors along the U.S. Atlantic and Pacific coasts. The objective of this field program was to characterize the types, relative amounts, and distributions of marine debris in representative harbors. This paper presents a summary of the results of the first nine surveys conducted under this program.

METHODS

Sample Collection

Floating debris often is observed concentrated in dense windrows, commonly referred to as debris slicks (EPA 1988), that appear to be influenced by surface currents and winds. Because the location, size, shape, and integrity of slicks were anticipated to be highly variable within each harbor, sampling was not conducted along predetermined transects but, rather, was directed toward the denser areas within the slicks.

Sampling at each harbor was conducted on 2 or 3 consecutive days between November 1988 and February 1989. Sampling dates and the total number of samples collected at each location are presented in Table 1.

The sampling plan for each location designated two or three areas within each harbor, based on criteria such as (1) presence of combined sewer overflows (CSO's) and stormwater outfalls in close proximity, (2) areas of heavy ship traffic or boating activity, (3) highly industrialized locations, and (4) areas that would represent overall debris conditions in the harbor. Because accumulated debris within the harbor is most likely to be transported out of the harbor with an outgoing tide, all sampling activities were initiated 1 to 2 h before ebb tide at each location. Selected areas within a harbor were sampled concurrently by deploying two or more small vessels.

Samples were collected by using a 0.33-mm mesh neuston net with dimensions of either 1 × 2 × 4, or 0.5 × 1 × 4, or 0.5 × 1 × 2 m. To minimize disturbances from the wake of the vessel, the net was towed from a boom positioned abeam of the vessel.

Sampling was conducted in slicks that were observed to be generally dense with floating debris. Each tow made through a slick was considered a single sample, regardless of the tow length. Generally, tows were conducted at a speed of 2 kn for approximately 20 min, or until a sample volume of approximately 80 L was collected. If more than one tow was made

Table 1.--Summary of harbor studies sampling activities, November 1988 through February 1989.

Location	Dates sampled	No. of samples
New York[a,b]	11, 12, 13 November 1988	43
Boston	2, 3, 4 December 1988	49
Philadelphia[a,c]	26, 27 January 1989	29
Baltimore[a]	29, 30 January 1989	29
Miami	3, 4, 5 February 1989	31
Tacoma[b]	15, 16, 17 February 1989	11
Seattle[a]	15, 16, 17 February 1989	6
Oakland	21, 22, 23 February 1989	12
San Francisco	21, 22, 23 February 1989	14
Total		224

[a]CSO's observed discharging.
[b]Rainfall $\geq$1 in.
[c]Spring high tide during sampling period.

within a slick, each tow sample was considered to be a replicate. Following each tow, the captured debris was collected and placed into labeled containers.

Meteorological conditions and the dimensions and location of each sampled slick were recorded on a sample-tracking form. Visual fixes of landmarks were used to plot tow locations on navigational charts.

Sample Processing and Analysis

All samples were processed and analyzed immediately after returning from the field. Prior to processing, all items in a sample were rinsed with tap water. Processing entailed separating all anthropogenic material from natural materials, and sorting and identifying the debris items by specific, descriptive categories (Fig. 1). Many of these categories were adapted from the national beach survey data card developed by the Center for Marine Conservation. All debris items within a category were counted and the totals were recorded on these or similar inventory or data sheets.

The data for each harbor sampling site were entered into a data base and the percent composition was calculated for each item or combination of items. Samples were photodocumented immediately upon return to the laboratory. All percentages discussed herein are calculated based on numbers of items found, not on weight or volume of the items.

RESULTS AND DISCUSSION

During this study, items were enumerated but they were not weighed or measured in any other manner. All cited percentages are based on the numbers of items found.

Attach Sample Label
Here

FLOATABLES SURVEY DATA INVENTORY SHEET

PLASTICS
Absorbant Material
Bags and Ties
  Bags ≤ 1-gal capacity
  Condiment bag
  Garbage bag tie
  Bags > 1-gal capacity
  Misc. bags
  Misc. pieces
  Vegetable sack
Banding Material
  Electrical wire tie
  Strapping band
Bottles
  Bottles ≤ 1-gal capacity
  Bottles > 1-gal capacity
  Beverage bottles
  Misc. bottles
  Misc. pieces
Caps and lids
  Caps/lids
  Cap/lid liners
  Cap/lid pieces
  Pull tab from plastic lid
Cigarette/Cigar Items
  Wrappers and packs
  Cigar tips
  Cigarette butts & filters
  Disposable lighters
Containers
  Lemon juice dispensers
  Misc. containers
Dishware
  Cups, spoons, forks, straws
  Dishes/plates
  Misc. pieces
Drug Paraphernalia
  Crack vial caps
  Crack vials w/caps
  Crack vials w/o caps
Fishing/Boating Items
  Floats & lures
  Fishing line-monofilament
  Netting
Food Wrappers--Misc.
Hair Care & Cosmetic Items--Misc.
Housewares & Tools--Misc.
Labels--Misc.
Line/Rope
  Filament
  Rope length ≤ 2 ft
  Rope length > 2 ft
Medical
  Band-aids
  Band-aid wrappers
  Cough syrup bottles
  Cylindrical tubes
  Cylindrical tube pieces
  Lip balm & containers

  Misc.
  Needle covers
  Pill vials & caps
  Syringes (whole)
  Syringes (pieces)
  Syringes with blood
  Tube ends only
  Vials
  Vial caps
Miscellaneous
  Foil wrappers (plastic-coated)
  Hardhat band
  Misc. Items
  Pieces
  Wrappers
  Polyvinylchloride (PVC)
  Toys
  Tubing
  Vials
Pellets & Spherules
  Pellets
  Spherules
Personal Hygiene
  Condoms (whole)
  Condoms (pieces)
  Diapers
  Panty liners
  Q-Tips (whole)
  Q-Tips (tubes only)
  Sanitary items
  Sanitary napkins
  Tampon applicators
  Tampon wrappers
Photographic Items
  Film containers
  Photos
Sheeting
  ≤ 2 ft
  > 2 ft
Six-Pack Holders
  Whole
  Pieces
Writing Utensils--Misc.

GLASS
Bottles
  Alcohol bottles
  Food bottles
Light bulbs
Misc. Pieces

PAPER
Bags
  Whole
  Pieces

(Continued on Reverse Side)

Cartons/Cardboard Boxes
  Whole
  Pieces
Food Items & Wrappers
  Beverage cartons
  Cups & plates
  Fast food wrappers
  Food wrappers
  Gum wrappers
  Lollipop sticks
Housewares Items & Tools
  Handi-wipes
  Matches
  Tar paper
Miscellaneous
  Cap liners
  Misc. items
  Misc. pieces
  Misc. wrappers
Sanitary Items
  Tissues
  Toilet paper

TEXTILES
Shoes--athletic
Canvas
Clothing--whole & pieces
Lint
Medical
  Cotton
  Cotton balls
  Linen
Rope

STYROFOAM
Band--pieces
Buoys & Floats
  Buoys
  Dock float pieces
Food Containers
  Beverage labels
  Cups & bowls (pieces)
  Cups & bowls (whole)
  Egg cartons
  Fast food containers (whole)
  Fast food containers (pieces)
  Plates & trays (pieces)
  Plates & trays (whole)
Miscellaneous
  Pieces smaller than a baseball
  Pieces larger than a baseball
  Polyurethane foam
  Spheres
  Stripping (possibly rubber)
  Wrappers
Packing Material
  Peanuts
  Misc.

RUBBER
Balloons
  Whole
  Pieces
Miscellaneous Items
  Misc. items
  Foam rubber
  Foam rubber stripping
  Pieces
  Tires & wheels
  Tubing
Rubberbands
  Pieces
  Whole

METAL
Cans
  Aerosol cans
  Beverage cans
Candy Wrappers
Foil
Gum Wrappers
Lids (Beverage)
Misc.
Twist Ties
Wheel Rims
Wire

WOOD
Burned Wood
Chips
Cork
Cut Lumber (2 x 4)
Ice Cream & Popsicle Sticks
Matches
Medical--Tongue depressors
Misc. Pieces
Pencils
Toothpicks

MISCELLANEOUS
Charcoal
Fibrous Material
Fish
Food Items
Grease Balls
Hair Balls
Insulation
Medical--Pills
Mothballs
Paint Chips
Plants
Slag
Soap
Sponge
String
Tar
Wax

Supplemental Sheet Yes ____ No ____
(Check One)

Figure 1.--Data inventory sheet showing descriptive categories. Form adapted from Center for Marine Conservation National Beach Survey Data Card.

All Cities

For all cities combined, 81% of all the debris collected was plastic or polystyrene (Fig. 2). Polystyrene, a plastic material, is treated separately based on its physical properties and uses. Miscellaneous debris, composed primarily of grease balls, tar, and slag, represented 12% of all debris. The remaining major debris categories (wood, paper, metal, rubber, glass, and textile) comprised approximately 7% of all debris. A summary of debris in each major category for each city and in all cities combined is presented in Table 2 and Figure 3.

The most abundant category of debris was plastic. Of the cities sampled, Tacoma had the greatest percentage of plastic (84%), due primarily to an unusually large number of plastic pellets/spherules collected in a single sample. Baltimore ranked second highest with 70%. Debris from Seattle contained the lowest percentage of plastic (41%).

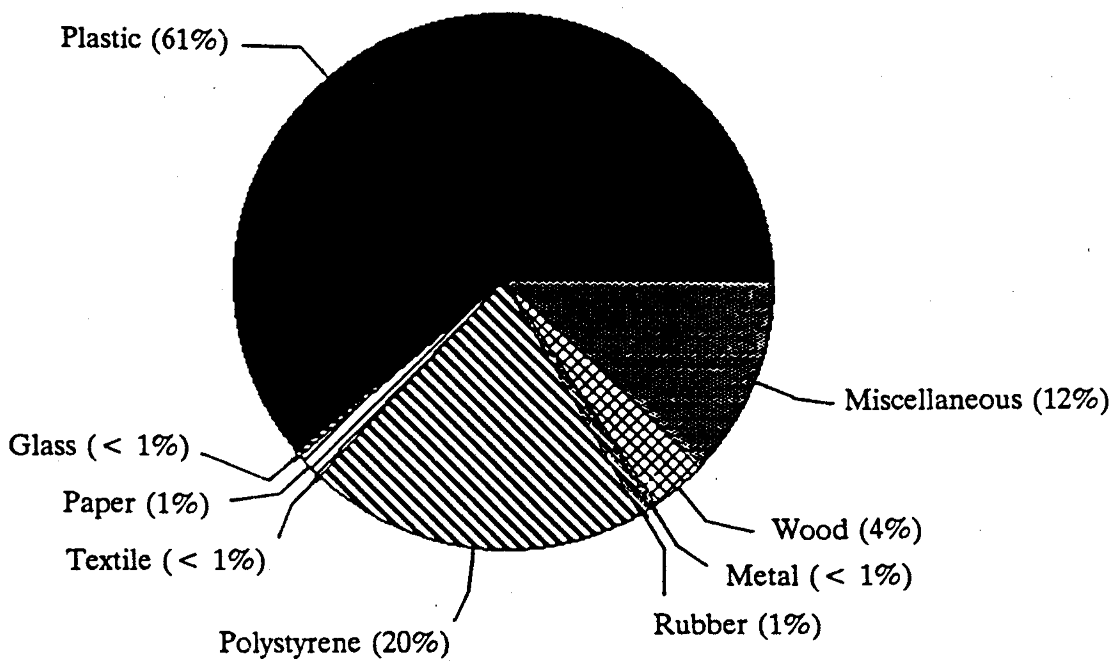


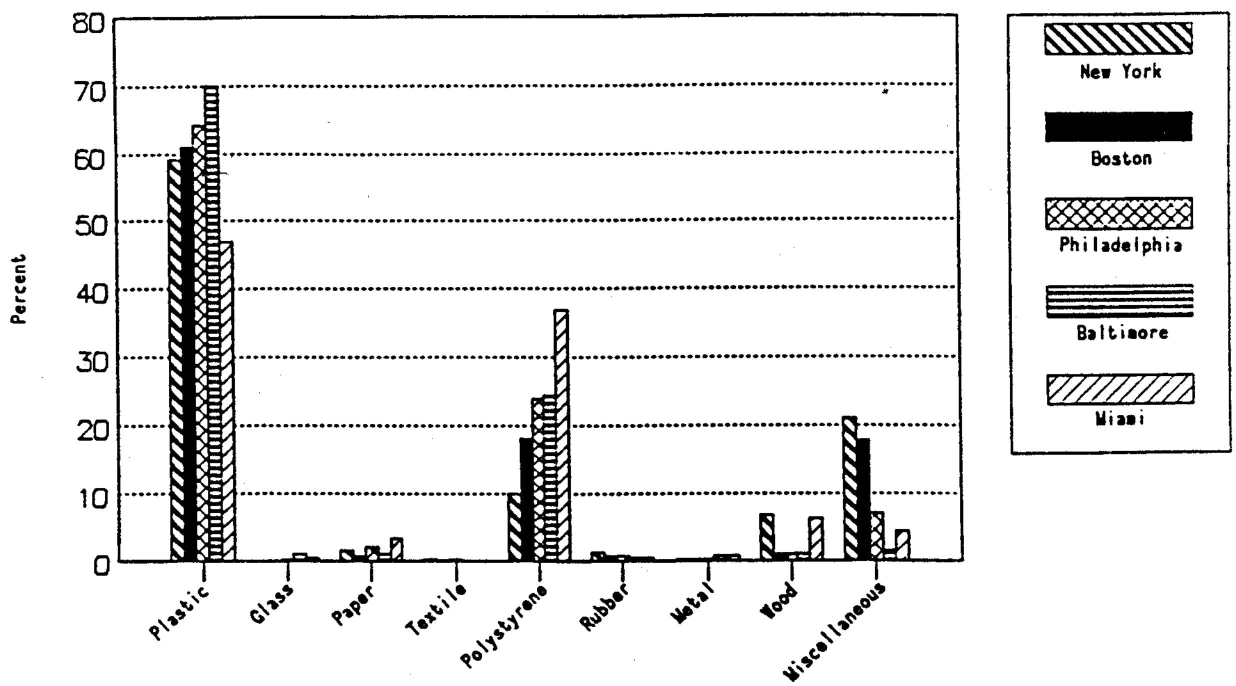
Figure 2.--Percent composition of all debris categories in all cities, November 1988 through February 1989. Percentages are based on the total number of items.

Table 2.--Summary of percent composition[a] of items of Environmental Protection Agency concern and all debris categories found in marine debris samples collected in U.S. harbors, November 1988 through February 1989. All percentages are rounded to the nearest tenth.

Composition	New York	Boston	Phila-delphia	Balti-more	Miami	Tacoma	Seattle	San Francisco	Oakland	All cities
Items of concern										
Pellets	19.5	29.7	34.0	19.5	24.0	85.5	16.4	16.8	29.7	30.4
Condoms	0.2	0.2	0.9	0.4	0.1	0.0	0.0	0.1	0.1	0.2
Tampons	0.2	0.1	0.5	0.2	0.0	0.0	0.0	0.0	0.0	0.1
Syringes or medical	0.1	0.1	0.1	0.6	0.1	0.0	0.0	0.1	0.0	0.1
Nets or traps	0.0	0.0	0.0	0.0	0.1	0.0	0.4	0.0	0.0	0.0
Line or rope	3.8	0.3	0.6	0.5	1.1	0.2	3.4	0.7	0.3	1.6
Six-pack yokes	0.1	0.1	0.3	0.3	0.7	0.0	0.1	0.1	0.1	0.1
Plastic bags or sheeting	4.8	1.9	9.1	16.0	17.3	1.6	8.0	5.3	9.2	6.3
Total	28.7	32.3	45.5	37.3	43.2	87.4	28.4	23.0	39.4	38.9
All categories										
Plastic	59.1	61.1	64.2	69.9	47.0	84.0	41.3	43.5	56.9	61.3
Glass	0.0	0.1	0.2	0.9	0.6	0.1	0.4	0.5	0.7	0.2
Paper	1.6	0.7	2.1	0.9	3.5	0.3	4.8	2.1	2.2	1.5
Textile	0.1	0.0	0.1	0.1	0.0	0.1	0.0	0.4	0.1	0.1
Polystyrene	9.9	18.2	24.0	24.5	37.0	12.6	43.6	46.9	34.6	20.3
Rubber	1.2	0.8	0.9	0.5	0.4	0.0	1.1	1.1	0.6	0.8
Metal	0.2	0.3	0.3	0.7	0.9	0.1	1.1	0.5	0.9	0.4
Wood	6.8	0.9	1.1	1.1	6.3	1.3	5.5	3.3	2.9	3.6
Miscellaneous	21.1	18.0	7.2	1.5	4.4	1.5	2.1	1.8	1.2	11.8

[a]Based on the total number of items found in each city.

ALL CATEGORIES



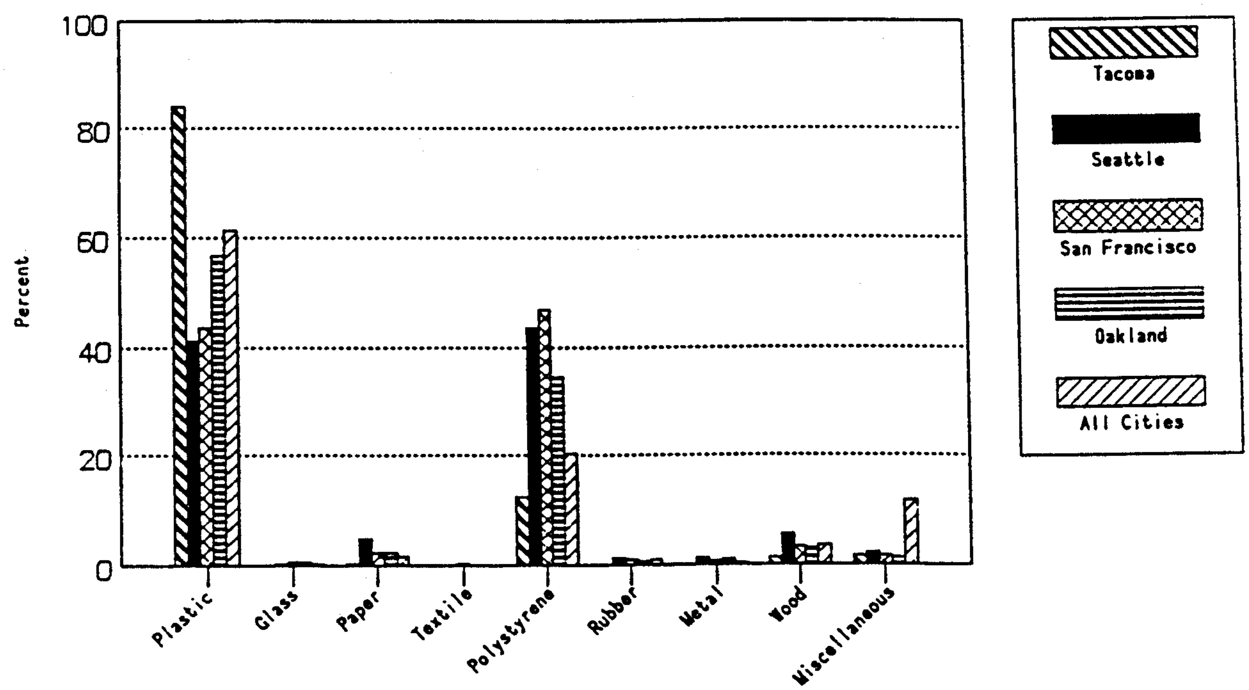


Figure 3.--Percent composition of all debris categories in each city. Percentages are based on the total number of items.

The second most abundant category of debris was polystyrene. Of the cities sampled, San Francisco had the greatest percentage of polystyrene (47%). Debris from New York contained the lowest (10%). The combined percentages of plastic and polystyrene debris found in each city are given in Figure 4.

The 10 most common items found in the study (Table 3) accounted for 75% of all debris. Four of these, plastic pellets/spherules, miscellaneous plastic pieces, polystyrene pieces smaller than a baseball, and cigarette butts were among the most abundant items found in all nine cities. Plastic pellets/spherules, the raw material, or resin, used in the manufacture of plastic products, constituted the most common item overall; it was also the most common item found in five cities (Boston, Philadelphia, Baltimore, Tacoma, and Oakland) and among the five most common items in two additional cities (New York and San Francisco).

In all, seven of the most abundant items were composed of plastic (five items) or polystyrene (two items). The two remaining categories include miscellaneous (two items) and wood (one item). The three most common types of plastic item included plastic pellets/spherules, miscellaneous plastic pieces, and plastic sheeting shorter than 0.6 m (2 ft). Plastic pellets/spherules comprised 26% of all debris collected. Miscellaneous plastic pieces (13%), and plastic sheeting shorter than 0.6 m (2 ft) (5%) ranked second and fifth overall. Polystyrene spheres (4%) and polystyrene pieces smaller than a baseball (10%) were also common.

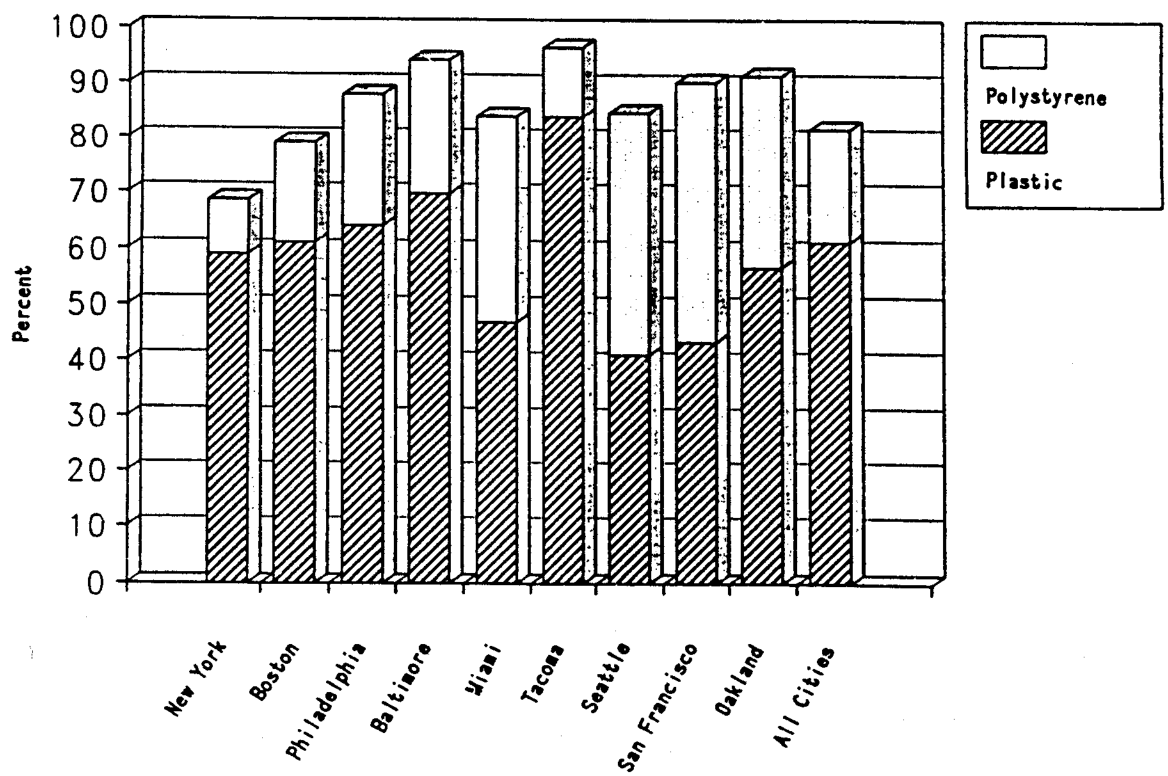


Figure 4.--Percent composition of plastic and polystyrene debris in each city. Percentages are based on the total number of items.

Table 3.--Summary of the most common items found in marine debris samples collected from all cities sampled, November 1988 through February 1989.

Category	Debris item	Quantity	Percent[a]
Plastic	Pellets/spherules[b]	11,406	25.90
Plastic	Miscellaneous pieces	5,785	13.14
Polystyrene	Pieces smaller than a baseball	4,350	9.88
Miscellaneous	Grease balls	2,696	6.12
Plastic	Sheeting <0.6 m (2 ft)[b]	2,100	4.77
Polystyrene	Spheres[b]	1,938	4.40
Plastic	Cigarette butts and filters	1,550	3.52
Miscellaneous	Slag	1,503	3.41
Plastic	Food wrappers	959	2.18
Wood	Miscellaneous pieces	923	2.10
Total of most common items		33,210	75.41
Total of all items in all cities		44,037	100.00

[a]Based on the total number of items found in each city.
[b]Item of Environmental Protection Agency concern.

The EPA-designated items of concern made up 39% of all debris (Fig. 5). They included the following items enumerated in this study:

- Pellets--Plastic pellets/spherules; polystyrene spheres.
- Condoms--Condoms (whole, pieces).
- Tampons--Tampons; tampon applicators; tampon wrappers.
- Syringes or medical--Syringes (whole, pieces, with blood); needle covers; vials and vial caps; insulin bottles.
- Nets or traps--Netting; floats and lures.
- Line or rope--Plastic rope (<0.6 m (2 ft) and >0.6 m (2 ft)); filaments; strapping bands; fishing line (monofilament); textile rope.
- Six-pack yokes (or similar)--Six-pack yokes (or similar) (whole and pieces).
- Plastic bags or sheeting--Plastic bags (<3.8 L (1 gal) and >3.8 L (1 gal)); condiment bags; miscellaneous plastic bags (whole and pieces); plastic sheeting (<0.6 m (2 ft) and >0.6 m (2 ft)).

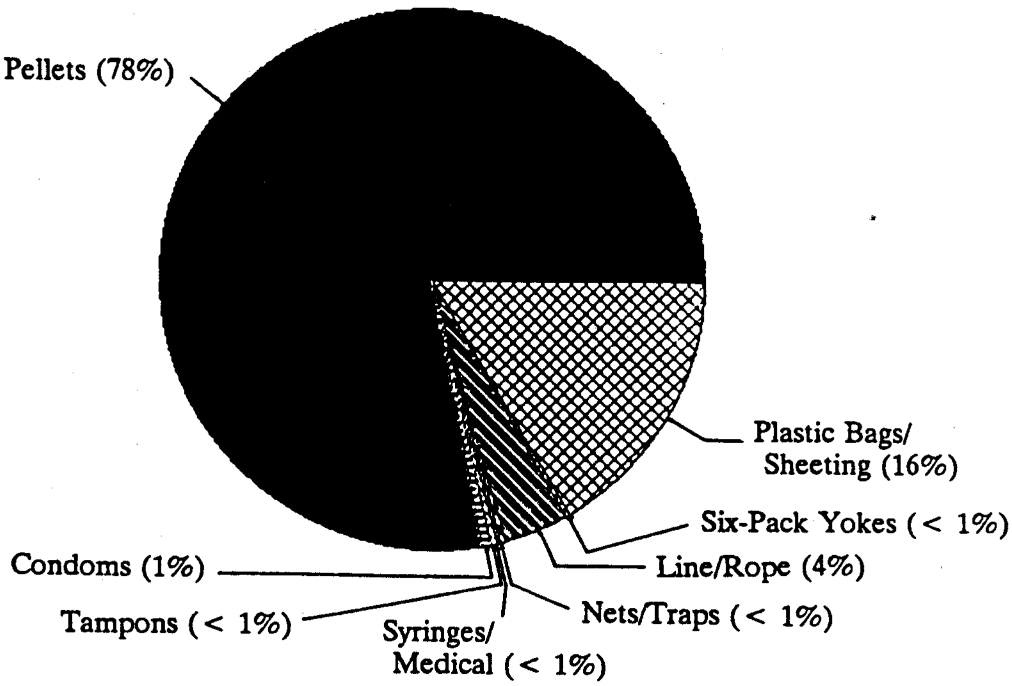


Figure 5.--Percent composition of items of Environmental Protection Agency concern in all cities. Percentages are based on the total number of items.

Items of concern constituted 87 and 46% of the total debris in Tacoma and Philadelphia, respectively. The lowest percentage of items of concern (23%) was found in San Francisco. Pellets were the most common item of concern found in all cities combined (30% of all debris and 78% of all items of concern), and ranged from 16% of all debris in Seattle to 86% of all debris in Tacoma. In all cities combined, plastic bags/sheeting was the second most common item of concern (6% of all debris; 16% of all items of concern).

Several debris items found during this study are typically associated with human sewage, medical waste, or illegal drug usage, as follows:

Sewage-related debris

Condoms (whole and pieces)	Tampons
Diapers	Tampon applicators
Panty liners	Tampon wrappers
Sanitary items	Fecal matter
Sanitary napkins	

Medical-related items

Syringes (whole and pieces)	Pill vials and caps
Syringes with blood	Cylindrical tubes (whole and pieces)
Needle covers	Tongue depressors
Vials and vial caps	Miscellaneous pills
Miscellaneous medical items	

Drug-related items
- Crack vials with caps
- Crack vials without caps
- Crack vial caps
- Illegal substances

Sewage-, medical-, and drug-related debris each comprised <1% of all items in each city (Table 4) except Philadelphia, where approximately 2% of the debris was sewage-related. Philadelphia, Baltimore, and New York had the highest percentages of all three types combined. The combination of these three types made up over 2% of the debris in Philadelphia, and more than 1% of the debris in Baltimore and New York. Exactly 1% of all debris found in all cities combined was sewage-, medical-, or drug-related.

Out of approximately 200 items identified, 26 items were common to all cities. These items were

Plastic
- Bags <3.8 L (1 gal) and >3.8 L (1 gal)
- Bottles <3.8 L (1 gal)
- Caps/lids (whole and pieces)
- Cigar/cigarette wrappers and packs
- Cigar tips
- Cigarette butts and filters
- Cups, spoons, forks, straws
- Food wrappers
- Filaments
- Rope shorter than 0.6 m (2 ft)
- Miscellaneous piece
- Pellets/spherules
- Sheeting <0.6 m (2 ft)
- Coffee stirrers

Paper
- Food wrappers
- Miscellaneous pieces

Polystyrene
- Cups and bowls (pieces)
- Pieces smaller than a baseball
- Peanuts
- Miscellaneous packing material
- Spheres

Wood
- Miscellaneous pieces

Miscellaneous
- Food items
- Grease balls

Of these items, seven items (plastic pellets/spherules, plastic bags >3.8 L (1 gal) and <3.8 L (1 gal), plastic filaments, rope shorter than 0.6 m (2 ft), and two types of polystyrene spheres) were items of EPA concern. None of these items was directly attributable to sewage-, medical-, or drug-related activities.

Table 4.--Number and percent composition[a] of sewage-, medical-, and drug-related debris.[b]

City	Sewage-related		Medical-related		Drug-related		Total[c]	
	Number	%	Number	%	Number	%	Number	%
New York	63	0.45	32	0.23	119	0.85	214	1.54
Boston	29	0.31	10	0.11	27	0.28	66	0.70
Philadelphia	45	1.59	2	0.07	21	0.74	68	2.40
Baltimore	40	0.92	27	0.62	6	0.14	73	1.68
Miami	4	0.14	3	0.10	1	0.03	8	0.27
Seattle	0	0.00	2	0.28	0	0.00	2	0.28
Tacoma	0	0.00	1	0.02	0	0.00	1	0.02
San Francisco	3	0.09	2	0.06	0	0.00	5	0.15
Oakland	1	0.07	1	0.07	0	0.00	2	0.02
Total	185	0.42	80	0.18	1 74	0.40	439	1.00

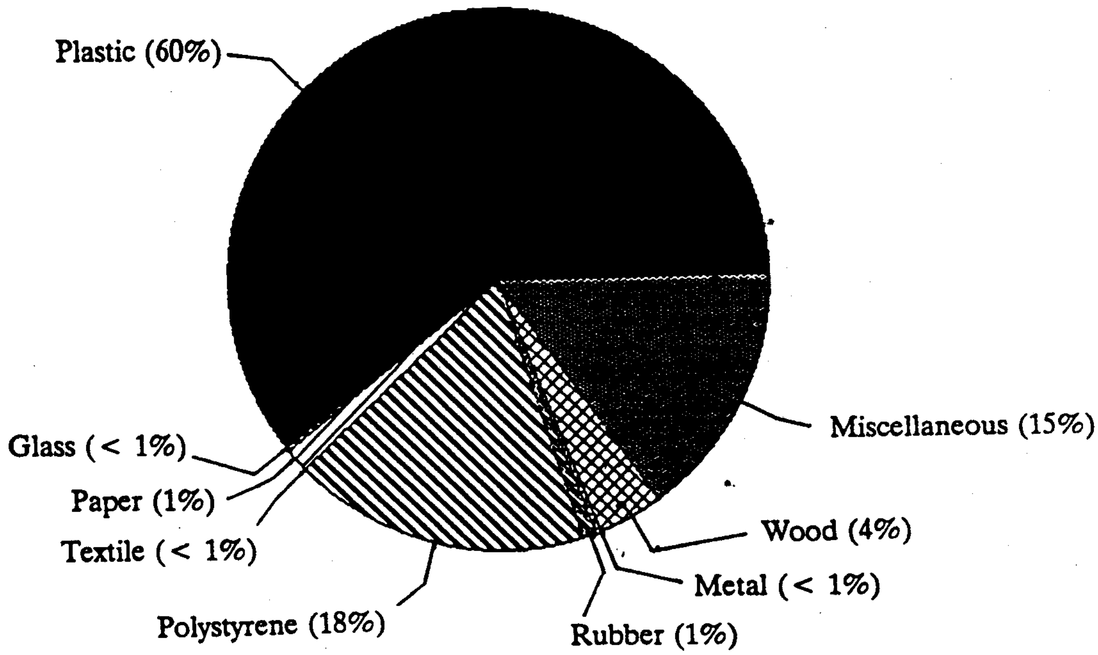
[a]Based on the total number of items found in each city.
[b]Defined in text.
[c]Sum of sewage-, medical-, and drug-related debris.

It is interesting to note that, of the 26 items listed above, 7 were related to food packaging or consumption and 3 were related to tobacco use. Food and tobacco generally are packaged in a wrapper or container when purchased; increasingly these containers or wrappers are being made of plastic. Disposal of these wrappers or containers is often careless, especially if the item is consumed during travel. In addition, the plastic wrappers are very lightweight and are easily transported by the wind. Either careless disposal by consumers or wind action over approved disposal sites such as dumpsters and trash receptacles could account for the presence of many plastic food and tobacco containers and wrappers.

East Coast Versus West Coast

Comparison of the results from east coast cities (New York, Boston, Philadelphia, Baltimore, and Miami) and west coast cities (Seattle, Tacoma, San Francisco, and Oakland), showed certain similarities and differences in debris composition (Figs. 6 and 7). Cities on both coasts had nearly the same percentages of plastic debris. Glass, paper, textile, rubber, and metal debris were found in low levels (<1%) on both coasts; these items were less common than wood debris, which was found in very similar proportions on both coasts. In contrast, east coast cities had a higher percentage of miscellaneous debris, which was primarily in the form of grease balls, tar, and slag. The contribution of polystyrene to the total debris was one to two times greater in the west coast cities than in the east coast cities.

ALL CATEGORIES



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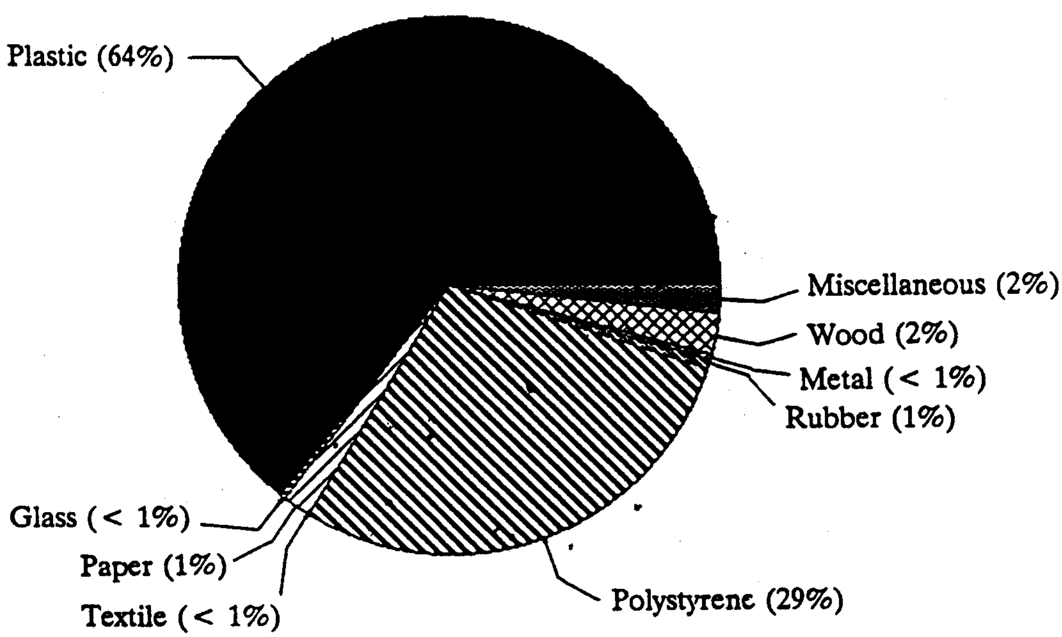
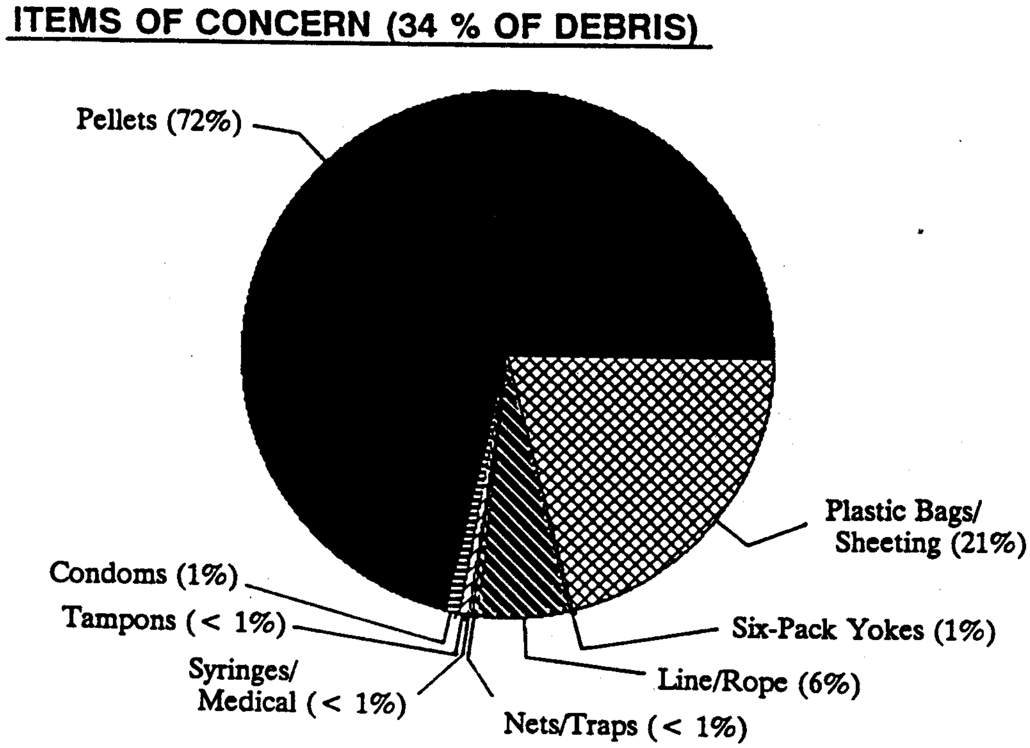


Figure 6.--Percent composition of all debris categories. (A) East coast cities. (B) West coast cities. Percentages are based on the total number of items.



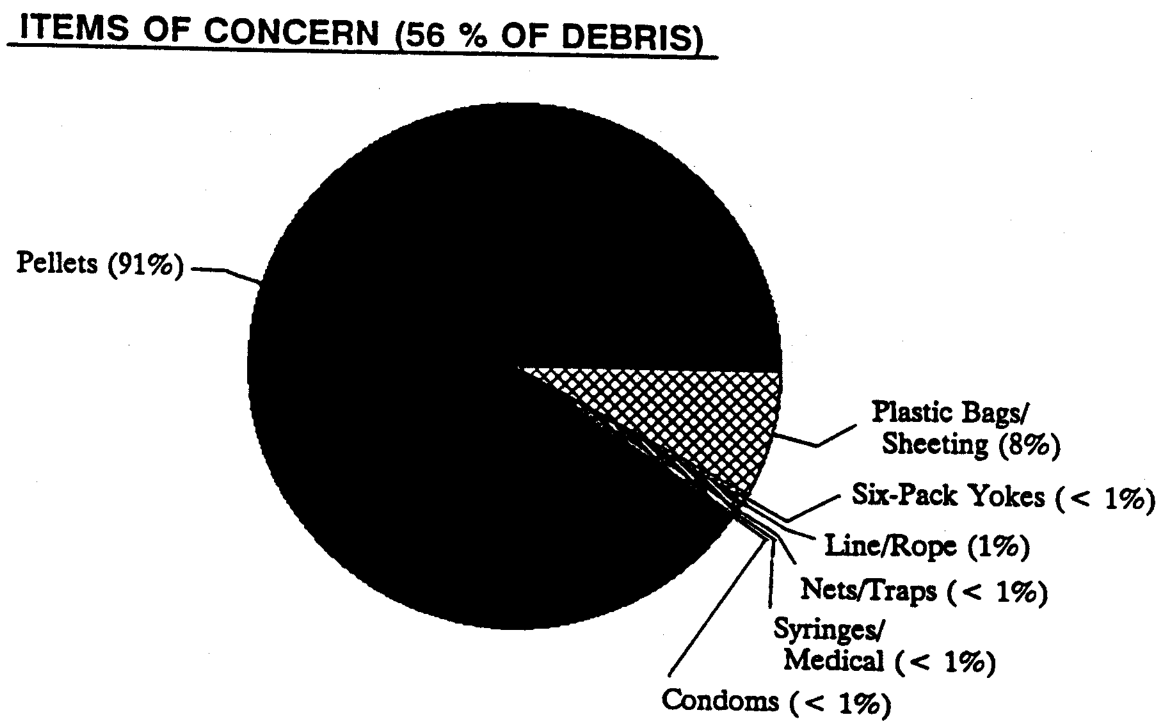


Figure 7.--Percent composition of items of Environmental Protection Agency concern. (A) East coast cities. (B) West coast cities. Percentages are based on the total number of items.

Over one-half of all debris items found in west coast cities were items of EPA concern, the majority of which were represented by pellets in Commencement Bay near Tacoma. Nearly one-third of the debris in eastern cities consisted of items of EPA concern, and approximately three-fourths of the items were pellets. Another item of EPA concern, plastic bags/sheeting, was common on both coasts, although proportionally greater on the east coast. Line/rope was more common on the east coast than on the west coast.

Sewage-, medical-, and drug-related debris were uncommon on both coasts (Table 4), and combined they totaled 1% of all debris found. Most of these three debris types were found in east coast cities. The larger presence of these on the east coast is likely to be due to the greater frequency of CSO and storm sewer discharges in eastern cities. No drug-related debris was found in the west coast cities.

Medical Debris

The greatest numbers of medical-related debris items were found in three east coast cities (Table 4): New York (32 items, or 0.23% of all New York debris), Baltimore (27 items, or 0.62% of all Baltimore debris), and Boston (10 items, or 0.11% of all Boston debris). A total of 7 syringes and syringe pieces, including 1 syringe containing blood, were found in New York; 7 syringes and pieces were found in Boston, and 13 syringes and pieces were found in Baltimore. Very little medical debris, only two items of which were syringes, was found in the remaining cities.

All of the syringes found during this study were the 1-cc insulin-dispensing type. In Baltimore, the needles typically were capped at one or both ends, probably indicating that they were used and disposed of by someone who had been instructed as to safe and proper syringe disposal. However, in New York and Boston the syringes usually were in pieces and not capped at either end.

SUMMARY

Plastic debris (including polystyrene) was numerically the largest component of marine debris in surface slicks from every city sampled. Plastic pellets were a significant portion of the plastic debris and were collected in every harbor. Several sewage-, drug-, and medical-related items were found during the study, but these items were not major components of the debris.

These surveys were the first in a continuing series of surveys sponsored under EPA's Harbor Studies Program. The program is providing the first semiquantitative evaluation of marine debris in U.S. harbors. Future surveys are being planned to study additional cities along the east and Gulf coasts, and many of the cities discussed in this study will be resampled.

ACKNOWLEDGMENTS

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The authors wish to thank all EPA and Battelle employees who assisted in sample collection and processing, tasks which were typically tedious and, at times, unpleasant. We also wish to thank Margarete Steinhauer for presenting this study at the Second International Conference on Marine Debris.

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PRELIMINARY REPORT ON THE DISTRIBUTION OF SMALL-SIZED MARINE DEBRIS IN SURUGA BAY

Mori Yukinawa and Shin-ichi Mio*
National Research Institute of Far Seas Fisheries
Fisheries Agency, the Government of Japan
Shimizu-shi, Shizuoka, 424 Japan

*Present address: Japan Sea National Fisheries Research Institute, Fisheries Agency, the Government of Japan, 1-5939-22, Suido-cho, Niigata-shi, Niigata, 951 Japan

ABSTRACT

From 17 to 29 March 1988, a survey to collect small marine debris was conducted in Suruga Bay. Tows (10-min) were made at 24 stations using a circular tow net with a diameter of 1.4 m and mesh size of 1.7 mm at the mouth and 0.5 mm at the cod end.

A total of 665 pieces of debris were collected during the survey. Of these, terrestrial debris and plants such as wood made up 50.1% of the total, followed in decreasing order by seaweed (19.5%), Styrofoam (13.8%), plastic sheets (13.2%), and other plastic pieces (3.3%).

Plastic sheet debris was found at most stations, whereas Styrofoam showed a tendency to accumulate in specific areas.

The distribution of each type of small debris corresponded well to the distribution of large debris observed by sightings conducted during the same cruise.

INTRODUCTION

Petrochemical products flowing and thrown into the sea are causing a number of problems. It has been pointed out that marine organisms swallow debris fragments together with their food. These fragments are generated when drifting petrochemical products in the sea are, in the process of their deterioration, broken up by physical factors such as waves. It is necessary to examine these small floating objects in order to understand the changes in size as well as the distribution and movement of drifting petrochemical products over the course of time.

In R. S. Shomura and M. L. Godfrey (editors), Proceedings of the Second International Conference on Marine Debris, 2-7 April 1989, Honolulu, Hawaii. U.S. Dep. Commer., NOAA Tech. Memo. NMFS, NOAA-TM-NMFS-SWFSC-154. 1990.

METHODS

This research was carried out at 24 stations in Suruga Bay from 17 to 29 March 1988 (Fig. 1). The nets used for collecting debris were 1.4 m in diameter. The first two-thirds of the net had a mesh size of 1.7 mm; the remaining third a mesh size of 0.5 mm. The net was towed for 10 min at a speed of 3 kn with the mouth of the net half submerged. Collected objects were immediately preserved in formalin and brought back to the laboratory, where they were counted and weighed and the information recorded. Those with maximal dimensions of 5 cm were excluded.

RESULTS

Major petrochemical products collected in this survey were fragments of plastic, plastic sheeting, and Styrofoam. Among the natural debris was terrestrial debris such as wood fragments and straw as well as drifting seaweed (Table 1). A total of 665 pieces of debris were collected. Debris deriving from petrochemical products accounted for 30.4% of the total (Styrofoam fragments 13.8%, fragments of plastic sheeting 13.3%, and plastic fragments 3.3%). Debris of terrestrial origin accounted for 50% of the total (the largest percentage), and seaweed for 19.5%. Plastic sheet fragments were extensively distributed, being collected at 66.7% of the 24 research stations (Fig. 1). The distribution of other plastic and Styrofoam was limited, occurring at only 29.2 and 20.8% of the stations, respectively. Natural debris of terrestrial origin was collected at 66.7% of the stations and seaweed at 62.5% of the stations.

Plankton, mainly Copepoda, sardine fry, and fish eggs were collected at all the research stations. These types of plankton numbered more than 1,000 at each station.

The highest densities of marine debris were found all across the middle of Suruga Bay. Research stations with high densities of plastic sheet fragments were continuous, as seen in the case of stations 12, 13, 22, and 17. A similar distribution pattern was observed for all drifting objects. The distribution of Styrofoam fragments was limited, but high densities were found in geographical positions similar to stations 7, 6, and 1.

Currents and winds were considered to be major factors in moving this debris. It has been reported that the surface current in Suruga Bay can be affected by the Kuroshio, which flows eastward off the bay. As shown in Figure 2, Inaba (1988) pointed out two such instances. The course of the Kuroshio during the survey period was more offshore, corresponding to Case 2 in Figure 2 (Meteorological Agency of Japan 1988). It is assumed that the flow of outer oceanic water is from west of the mouth of the bay and divides into two currents near the center of the bay, with one current moving around the mouth of the bay clockwise and the other moving counterclockwise toward the inner side of the bay. The area of the highest densities of marine debris is on the boundary between these currents, which would represent a front. Strong northeast winds were blowing for several days during the survey period, but the distribution of marine debris was considered to be affected more by surface currents than by the winds.

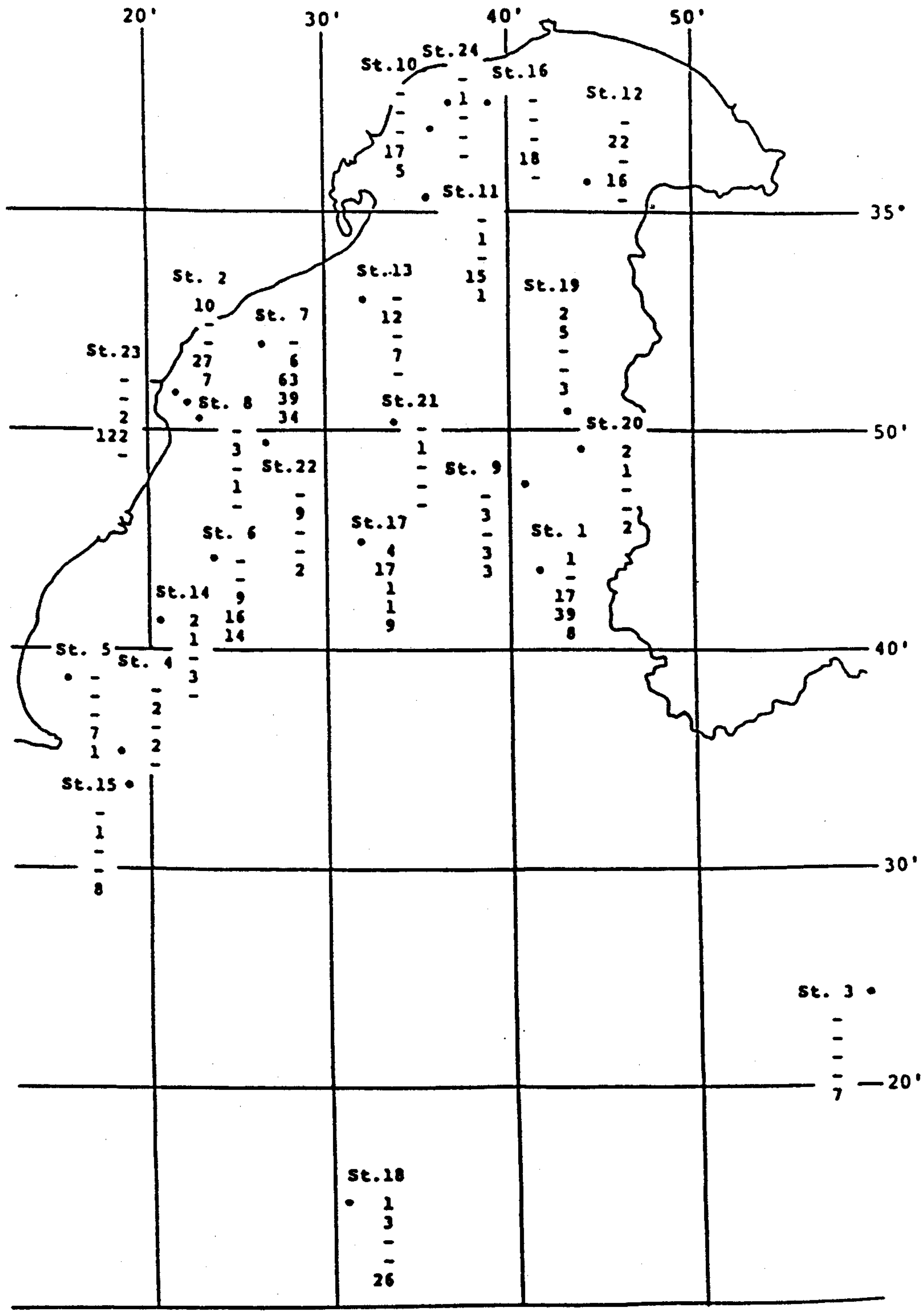

Figure 1.--Stations (St.) and data collected in minute marine debris survey. At each station, numbers from the top down indicate plastic pieces, plastic sheets, Styrofoam, land plants, and seaweed, in that order.

Table 1.--Sampling location and composition of minute marine debris in Suruga Bay.

Station	Time	Latitude N	Longitude E	Plastic pieces	Plastic sheets	Styrofoam	Land plants	Seaweed	Copepoda	Eggs	Larvae
1	12.50	34°43.72′	138°41.68′	1	--	17	39	8	42	10	--
2	7.17	34°51.19′	138°22.56′	10	--	--	27	7	--	--	--
3	11.56	34°24.30′	138°59.13′	--	--	--	--	7	--	3,230	--
4	16.42	34°36.32′	138°18.60′	--	2	--	2	--	58	--	7
5	7.10	34°37.30′	138°16.22′	--	--	--	7	1	1,120	84	--
6	11.04	34°43.58′	138°22.92′	--	--	9	16	14	15	--	--
7	16.40	34°54.90′	138°28.68′	--	6	63	39	34	--	--	--
8	7.17	34°50.75′	138°22.01′	--	3	--	1	--	37	--	--
9	11.35	34°47.72′	138°40.85′	--	3	--	3	3	25	154	--
10	14.42	35°04.05′	138°34.32′	--	--	--	17	5	--	--	--
11	9.11	35°02.33′	138°32.60′	--	1	--	15	1	26	15	--
12	10.31	35°02.70′	138°44.63′	--	22	--	16	--	15	46	--
13	12.45	34°57.33′	138°32.44′	--	12	--	7	--	25	12	--
14	17.05	34°41.56′	138°20.30′	2	1	--	3	--	43	82	--
15	7.44	34°34.05′	138°19.06′	--	1	--	--	8	--	--	--
16	11.54	35°05.48′	138°37.65′	--	--	--	18	--	22	57	--
17	17.03	34°45.49′	138°32.08′	4	17	1	1	9	121	15	--
18	12.02	34°14.81′	138°30.55′	1	3	--	--	26	--	19	34
19	16.32	34°51.26′	138°43.14′	2	5	--	--	3	12	38	--
20	7.11	34°48.68′	138°44.37′	2	1	--	--	2	--	--	1,540
21	7.25	34°50.28′	138°37.42′	--	1	--	--	--	--	3	--
22	12.08	34°49.17′	138°26.96′	--	9	--	--	2	--	--	6
23	7.14	34°51.66′	138°22.70′	--	--	2	122	--	--	--	6
24	13.03	34°05.22′	138°36.72′	--	1	--	--	--	--	--	5

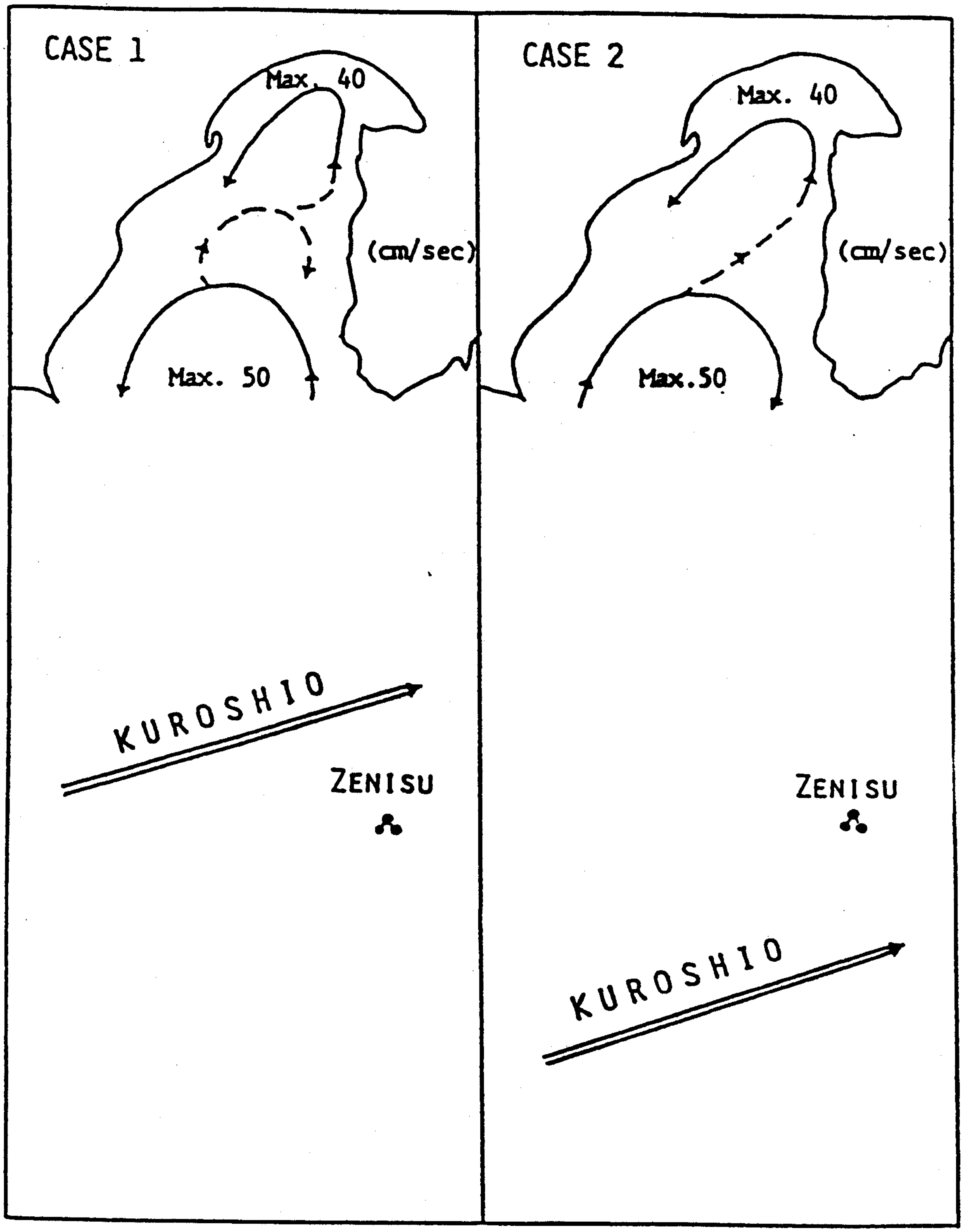

Figure 2.--Diagram showing the relationship of the Kuroshio to the surface current of Suruga Bay (Inaba 1988).

Plankton and marine debris showed an inverse correlation. Areas where plankton were found in large quantities were influenced a great deal by the open ocean. It is reasonable to assume that plankton and marine debris showed different distributions because the plankton, being totally submerged are not influenced at all by the wind.

Small floating objects were found most frequently in areas influenced heavily by coastal currents. The distribution of drifting petrochemical product fragments corresponded well to that of the larger floating objects. It is therefore conjectured that petrochemical products drifting in the sea gradually deteriorate and are broken into small fragments.

More detailed studies will be needed to find out the distribution and abundance of Styrofoam fragments.

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DISTRIBUTION, ABUNDANCE, AND SOURCE OF ENTANGLEMENT DEBRIS AND OTHER PLASTICS ON ALASKAN BEACHES, 1982-88

Scott W. Johnson
Alaska Fisheries Science Center Auke Bay Laboratory
National Marine Fisheries Service, NOAA
Auke Bay, Alaska 99821, U.S.A.

ABSTRACT

Sixty kilometers of outer coast beaches at 25 locations in Alaska were surveyed from 1982 to 1988 to determine distribution, composition, quantity, deposition, and source of plastic debris washed ashore. Approximately 67% of all plastic debris found was fishing gear (e.g., net fragments, rope, floats) and 33% was packaging material (e.g., plastic bags, bottles). Debris found which could entangle marine mammals, seabirds, and fish included trawl web, rope, packing straps, and monofilament gillnet. Monofilament gillnet was not abundant (usually <5 pieces/km) on beaches, but trawl web was found on beaches throughout Alaska and exceeded 10 fragments/km at more than 50% of the locations sampled. Foreign fisheries were the source of most (98%) of the monofilament gillnet washed ashore; the source of trawl web is shifting from foreign to domestic fisheries.

Trends in composition and abundance of plastic debris were monitored at three sites: Amchitka Island, Middleton Island, and Yakutat. Amchitka Island had similar quantities (~300 items/km) of total plastics in 1982 and 1987, although the amount of trawl web at this site continued to increase. Quantities of plastic debris on Middleton Island remained similar from 1984 to 1987 (average 860 items/km), with the exception of an approximate 33% decline in 1985 from the 4-year average. Near Yakutat, the quantity of trawl web deposited ashore increased from 8.8 to 10.1 fragments/km/year from 1985 to 1988. Continuing the surveys of these benchmark beaches will help determine whether recent mitigating legislation is effective in reducing the disposal of entanglement debris and other plastics at sea.

INTRODUCTION

Marine pollution has become a major environmental concern in the 1980's. One form of marine pollution that has attained international attention is plastic debris discarded or lost in the world's oceans.

In R. S. Shomura and M. L. Godfrey (editors), Proceedings of the Second International Conference on Marine Debris, 2-7 April 1989, Honolulu, Hawaii. U.S. Dep. Commer., NOAA Tech. Memo. NMFS, NOAA-TM-NMFS-SWFSC-154. 1990.

Plastics are of particular concern because they persist in the environment for years, endangering marine animals and man. Seabirds and sea turtles can ingest pieces of plastic that block their digestive tracts (Balazs 1985; Day et al. 1985); seabirds, fish, and invertebrates can become entrapped in derelict gillnets (DeGange and Newby 1980; High 1985); marine mammals can become entangled in fragments of trawl web, packing straps, and rope (Fowler 1987; Stewart and Yochem 1987); and ships can be disabled from plastic debris which fouls props or cooling intakes (Wallace 1985).

Most plastics are lightweight, float at or near the ocean surface, and often wash ashore. Plastic debris is common on Alaskan beaches because of the loss or discard of fishing gear (e.g., trawl web, rope, and floats) and other plastic debris from large commercial fishing fleets operating in the North Pacific Ocean and Bering Sea (Merrell 1985; Uchida 1985). Plastic debris washed ashore represents, to some degree, the types and quantities lost or discarded at sea. Beach surveys may be the best method of evaluating whether recent mitigating legislation (MARPOL Annex V) to reduce the input of plastics into the sea is effective.

The National Marine Fisheries Service (NMFS) has conducted beach surveys for plastic debris on Alaskan beaches periodically since 1972. The objective of this paper is to examine recent trends in the distribution, composition, quantity, deposition, and source of plastic debris on Alaskan beaches based on surveys from 1982 to 1988; the emphasis was on entanglement debris (trawl web, gillnet, rope, and packaging straps) at study sites that were repetitively sampled since 1982. The occurrence of trawl web is discussed in detail because it is one of the most abundant entanglement debris items found on Alaskan beaches (Merrell and Johnson 1987; Johnson and Merrell 1988), and it is the principal item entangling northern fur seals, *Callorhinus ursinus*, on the Pribilof Islands (Fowler 1987). Additional information on past NMFS studies can be obtained from Merrell (1980, 1984, and 1985).

METHODS

Approximately 60 km of outer coast beaches at 25 locations in Alaska have been surveyed for plastic debris since 1982 (Fig. 1). Locations of beaches surveyed at least twice as benchmarks include: Amchitka Island in the Aleutians; Middleton Island in the central Gulf of Alaska; and beaches near Yakutat in the eastern Gulf of Alaska (Fig. 1).

Beaches were surveyed primarily during summer (June-September) in all locations with the exception of those near Yakutat. Ten beaches on Amchitka Island were surveyed once in September 1982 and again in September 1987; three beaches on Middleton Island were surveyed once in either July or early August 1984 through 1987; and eight beaches near Yakutat were surveyed once in September 1985, four times in 1986 and 1987 (January, April, July, September), and twice in 1988 (March and September). Five of the eight Yakutat beaches were surveyed once in September 1984.

Survey methods were similar for all beaches (Merrell 1985). Most beaches were 1 km in length. The survey area for each beach included the

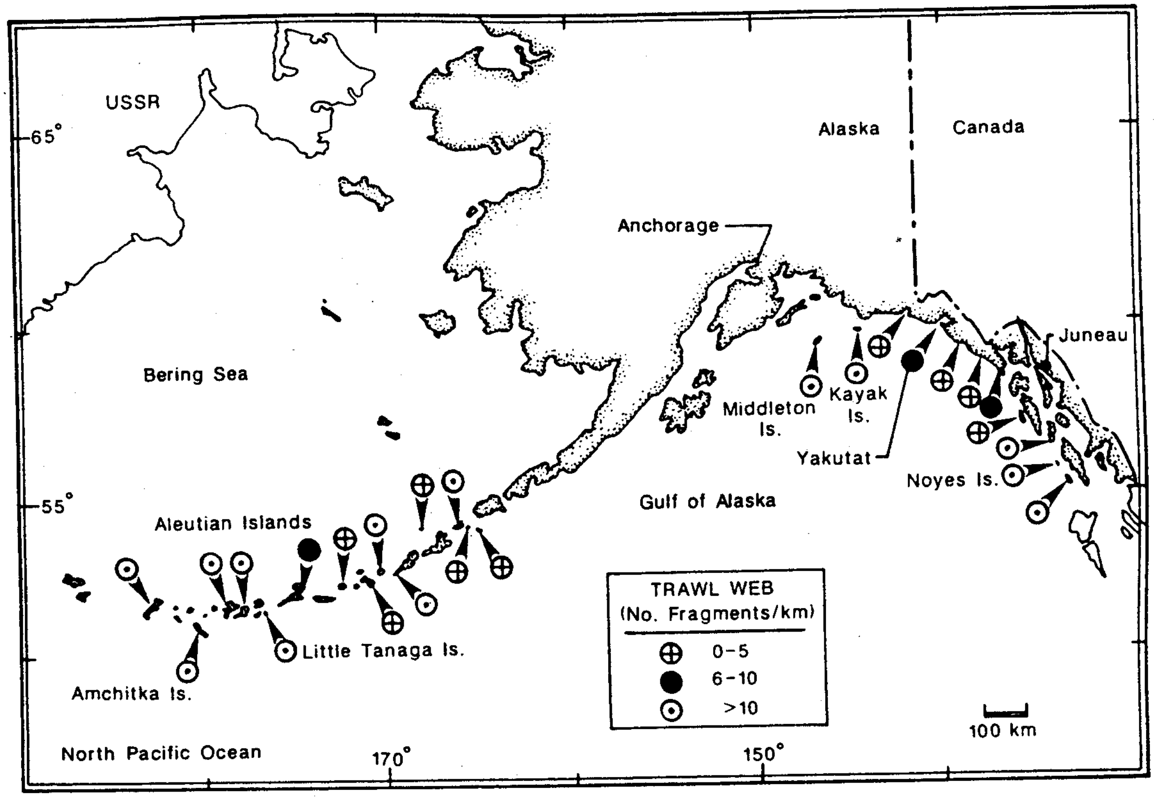

Figure 1.--Locations of beaches surveyed for plastic debris and quantity of trawl web fragments (number per kilometer) found in Alaska, 1982-88.

intertidal zone between the water's edge and the seaward limit of terrestrial vegetation at the upper limit of normal high tide. All plastic debris visible from walking height was counted (i.e., pieces $\geq$5 mm, and trawl web and monofilament gillnet fragments with five or more complete meshes). Rope of any diameter was counted if it was $\geq$1 m in length. We did not count pieces (e.g., gillnet floats and plastic bottles) if they were less than one-half their original size. We either weighed or estimated the weight of trawl web fragments depending on size and location: whether they were loose on the beach, buried, or snarled on drift logs. Stretch mesh was measured (knot to knot inside measure) for one representative mesh of each net fragment sampled. We did not search for debris within piles of drift logs or seaweed.

Beginning in 1985, all trawl web fragments at Yakutat were tagged with a small metal tag or removed and discarded inland from the beach. Trawl web fragments that were tagged and remained onshore could therefore be distinguished from new (not tagged) fragments, making it possible to determine deposition by season and year. At Middleton and Amchitka Islands, trawl web and gillnet fragments were painted with orange dye so that they could be identified in future surveys.

To determine trends in accumulation of all types of plastic debris, a 1-km beach on Middleton Island was cleared of all surface debris annually from 1984 to 1987. Debris was moved to terrestrial areas above the high-tide zone. Debris too large to move, partially buried, or snarled on drift logs was marked with paint, flagging, or tags for identification in future surveys.

The only major change in the sampling procedure was made in 1986 and 1987 when all beaches were subdivided into ten 100-m increments, thereby providing ten different data sets for each 1-km beach. This change was designed to improve the statistical precision of debris estimates (Ribic and Bledsoe 1986).

Differences in quantities of entanglement debris items on Amchitka Island were tested by paired t-tests, where observations in 1982 and 1987 were paired for each of ten 1-km beaches. Differences in quantities of individual debris items between Amchitka and Middleton Islands in 1987 were tested by t-tests. The association between quantity of trawl web and total plastic debris found on Alaskan beaches was determined by linear correlation.

RESULTS

Derelict trawl web was found on sampled beaches throughout Alaska (Fig. 1). At over 50% of the locations sampled, trawl web exceeded 10 fragments/km of beach. Locations with the highest quantities of trawl web included Little Tanaga Island in the Aleutians (216 fragments/km), Kayak Island in the central Gulf of Alaska (92 fragments/km), Amchitka Island (55 fragments/km), and Noyes Island in southeast Alaska (53 fragments/km) (Fig. 1).

Trawl web was significantly correlated ($\underline{P} < 0.05$; $r = 0.37$) with the quantity of total plastic debris (all types) found per kilometer of beach. Thus, beaches that accumulated many fragments of trawl web generally also accumulated numerous other plastics. Locations with the highest quantities of total plastics included Noyes Island (1,330/km), Kayak Island (1,142/km), and Middleton Island (988/km) (Fig. 1).

Composition of total plastic debris (based on number of individual items) on Amchitka Island beaches was similar in 1982 and 1987. Likewise, composition of plastic debris on Middleton Island was similar in all years (1984-87). At both locations in 1987, nearly two-thirds of all items found were derelict fishing gear (Table 1).

Quantities of entanglement debris changed on Amchitka Island from 1982 to 1987, but only rope increased significantly ($\underline{P} < 0.05$) (Fig. 2). Trawl web, strapping, gillnet, and gillnet floats (possible indicator of quantity of gillnet lost), either increased or decreased, but not significantly (Fig. 2). Because some items increased and some decreased, total plastics were similar in 1982 and 1987 (~300 items/km).

Table 1.--Percent composition of derelict fishing gear based on number of plastic debris items found on Amchitka and Middleton Islands, Alaska, 1987.

Debris items	Percent of total			
	Amchitka		Middleton	
Derelict fishing gear	68		62	
Rope		31%		7%
Trawl web		26%		4%
Floats		20%		82%
Straps		16%		3%
Gillnet		1%		1%
Miscellaneous		6%		3%
Packaging material	28		35	
Personal effects	2		2	
Miscellaneous	2		1	

The number of trawl web fragments found on Amchitka Island beaches has steadily increased since 1972 (Fig. 3); the average weight of individual fragments, however, has decreased from 11 kg in 1974 to 4 kg in 1987. The frequency of occurrence of different trawl web mesh sizes measured on Amchitka Island was similar in 1982 and 1987 (Fig. 4). In both years, the most common mesh size was 101-150 mm; approximately one-third of the fragments had mesh sizes >150 mm.

Quantities of entanglement debris remained relatively stable on Middleton Island from 1984 through 1987 (Fig. 5). During these 4 years, trawl web averaged 24 fragments/km of beach; rope, 51 pieces/km; straps, 16/km; and gillnet fragments, 4/km. Gillnet floats increased 58% from 287/km in 1984 to 454/km in 1987. Total plastics found on Middleton Island were similar in 1984, 1986, and 1987. In 1985, however, there was a 33% decline in total plastics from the 4-year average of 860 items/km (Fig. 5). Differences in quantities of debris by location were evident between Middleton and Amchitka Islands in 1987 (Table 2). Significantly ($\underline{P} < 0.05$) more trawl web was found on Amchitka than on Middleton Island, whereas significantly ($\underline{P} < 0.001$) more gillnet floats and total plastics were found on Middleton Island. Although not significant, twice as much gillnet was found on Middleton Island as on Amchitka Island.

A 1-km beach on Middleton Island, cleared of all plastic debris annually from 1984 to 1987, accumulated debris quickly, sometimes within 1 year (Fig. 6). Trawl web, gillnet, and rope, cleared from this beach in 1986, accumulated to previous or higher quantities by 1987. Entanglement debris accumulated in a similar proportion each year; rope was the most abundant, usually followed by trawl web, gillnet, and closed straps (Fig. 6).

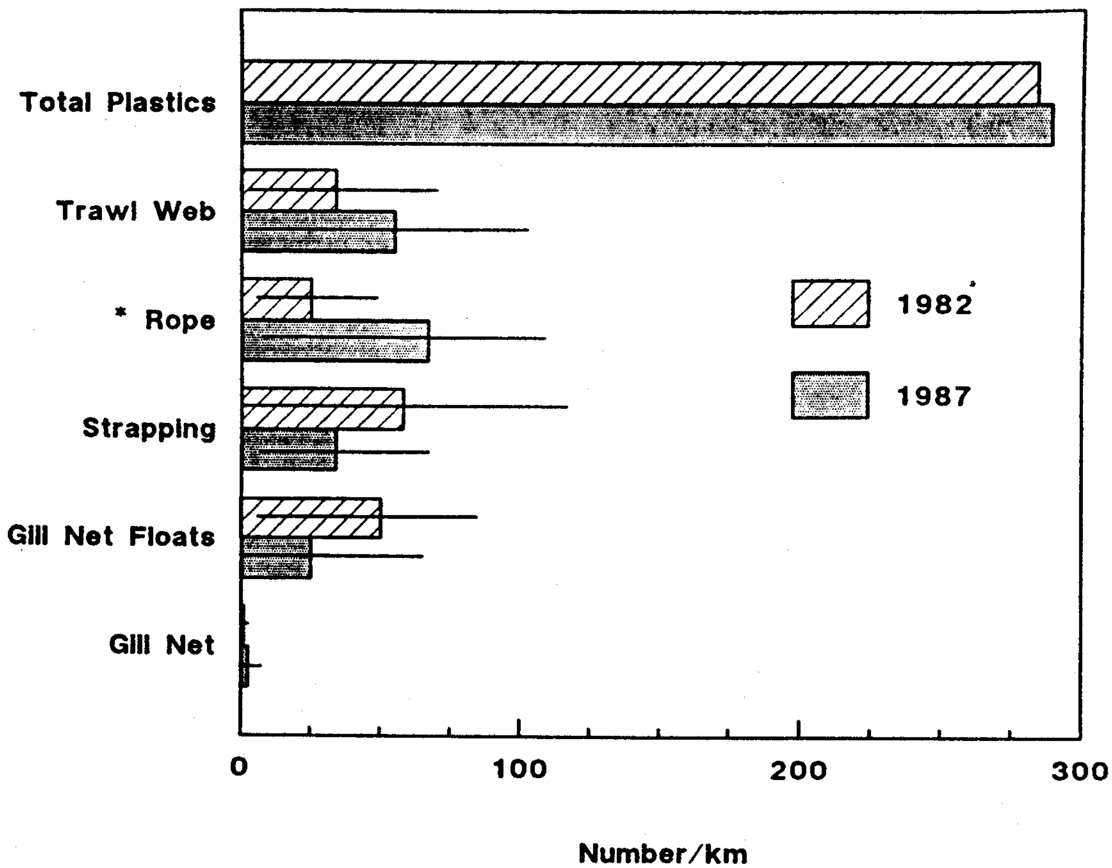

Figure 2.--Quantities (mean ±SD) of entanglement debris and total plastics found on Amchitka Island, Alaska, in 1982 and 1987. Data based on ten 1-km beaches. Asterisk denotes significant difference between years $P < 0.05$.

Total deposition of trawl web at Yakutat was similar from 1985 to 1988 (range 8.8 to 10.1 fragments/km/year) (Table 3). More fragments, however, washed ashore during the fall-winter months (Oct.-Apr.) than the spring-summer months (May-Sept.). Of the beach locations examined more than once, deposition of trawl web was greatest on Amchitka Island, followed by Middleton Island and Yakutat. Some locations, such as Little Tanaga Island, Kayak Island, and Noyes Island, accumulated more trawl web than the above or adjacent locations, probably because of their favorable orientation to major ocean currents, prevailing storm winds, or increased fishing effort and loss of gear in nearby waters.

At present, the source of trawl web washed ashore is shifting from foreign vessels to domestic vessels as U.S. trawl fisheries replace foreign trawl fisheries in the North Pacific Ocean and Bering Sea in the latter 1980's (Cotter et al. 1988) (Fig. 7). Most (98%) monofilament gillnet washed ashore, however, is from foreign high seas fisheries (Fig. 7) because monofilament nylon gillnets, with the exception of a small herring fishery, are banned in Alaska (Uchida 1985). The most common (42%) mesh size of gillnet washed ashore was 110 mm stretch mesh (Table 4). Based on mesh

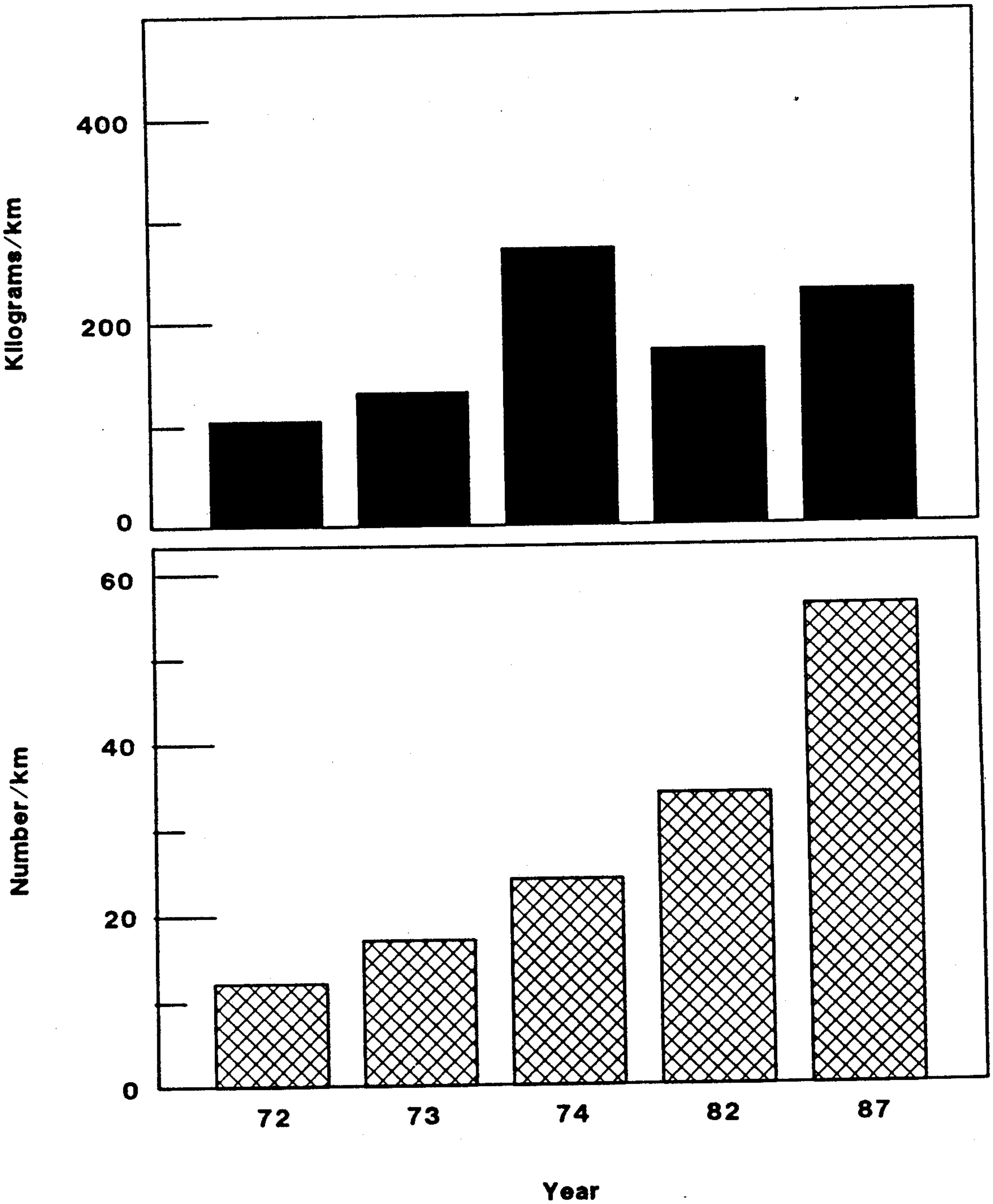

Figure 3.--Number and weight of trawl web fragments found on Amchitka Island, Alaska, from 1972 to 1987. Ten 1-km beaches surveyed in each year. Data for 1972-74 from Merrell (1985).

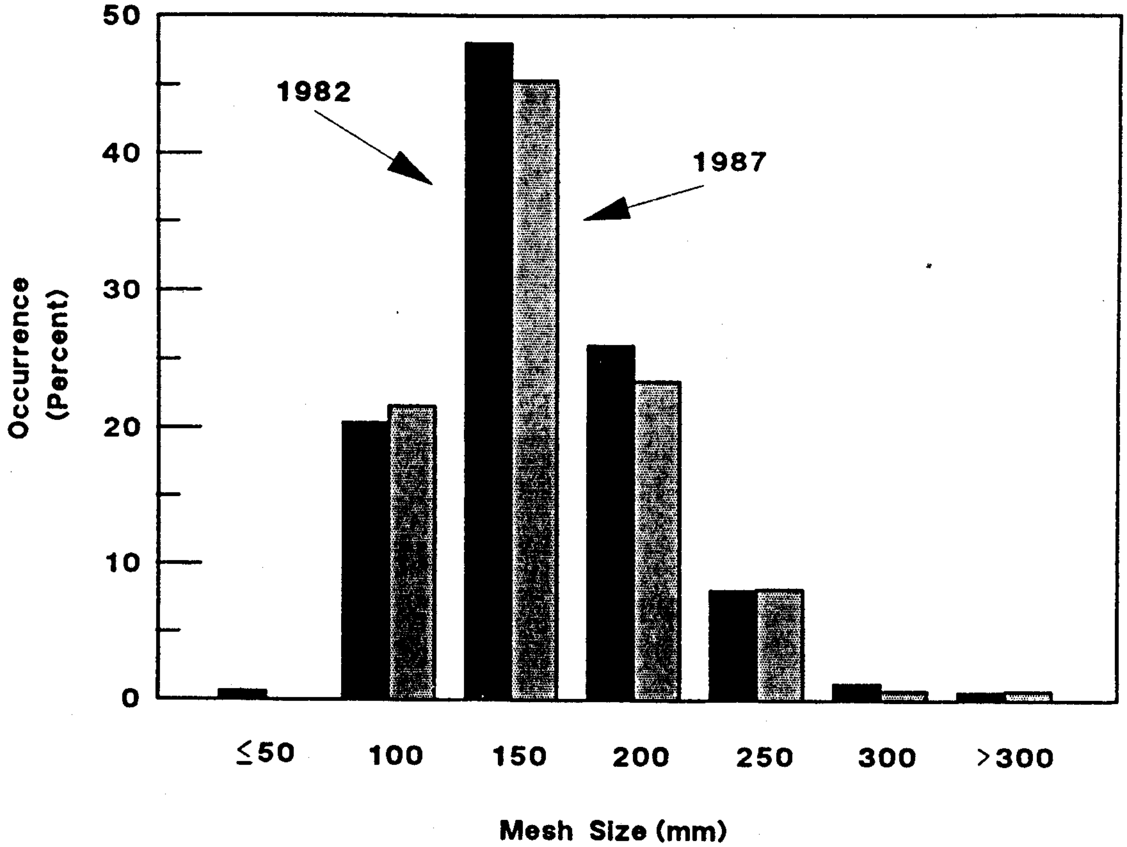

Figure 4.--Percent occurrence of different mesh sizes of trawl web fragments found on Amchitka Island, Alaska, in 1982 (n - 333) and 1987 (n - 282). The X-axis label is upper limit of interval.

size, likely sources of foreign gillnet are high sea fisheries (Japan, Taiwan, Korea) for squid and salmon (Merrell 1985; Uchida 1985).

DISCUSSION

The widespread distribution and continual accumulation of plastic debris on outer coast beaches of Alaska are indicative of the vast quantities of debris lost or discarded into the North Pacific Ocean and Bering Sea. Annually, an estimated 1,664 metric tons of plastic debris are lost or discarded from fishing vessels in Alaskan waters (Merrell 1980). Although large quantities of plastic debris were found on many Alaskan beaches, it was not evenly distributed. Some beaches with large quantities of trawl web (>10 fragments/km) and other plastic debris were adjacent to locations with small quantities of debris (Fig. 1). Accumulation of debris on beaches depends upon the orientation of the beach to major ocean currents and prevailing winds. Even within a given location, debris abundance can differ dramatically; the windward side of Middleton Island, for example, had 15 times the amount of debris found on the leeward side of the island (Johnson and Merrell 1988). Thus, when interpreting results

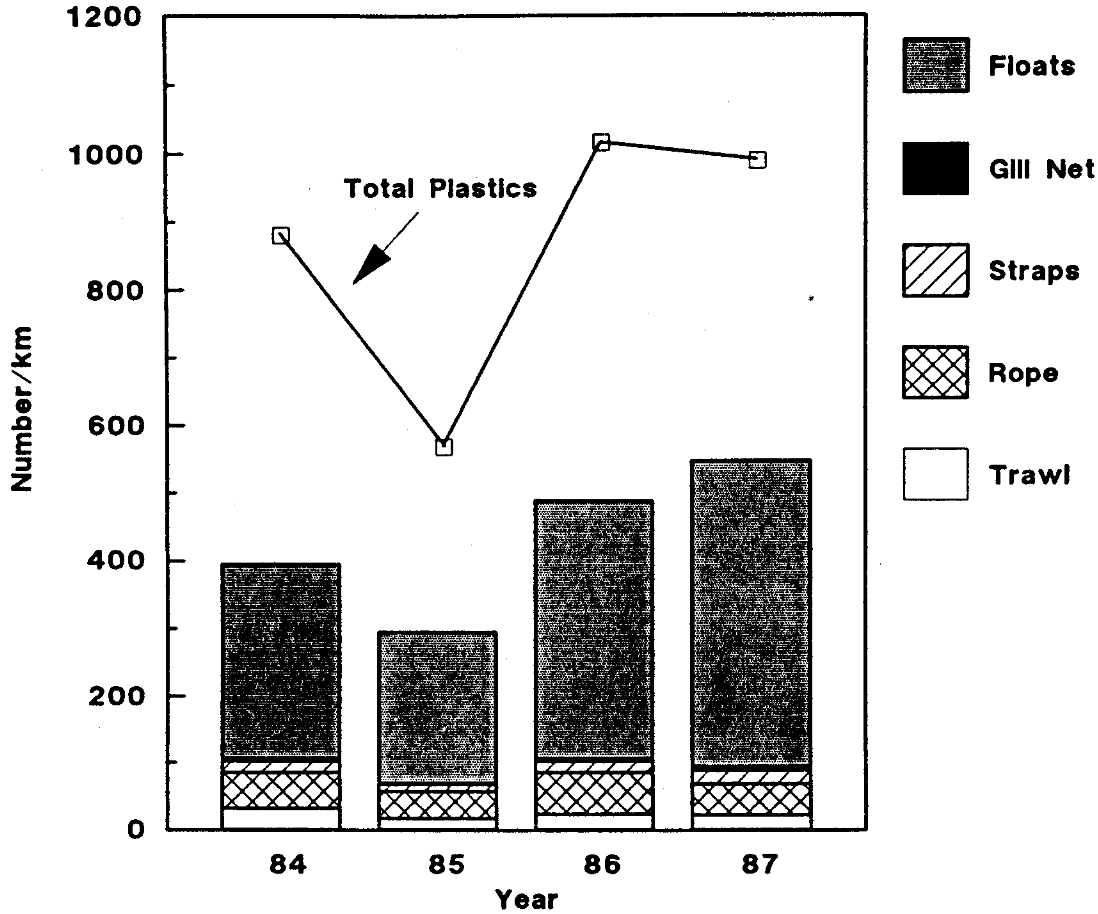

Figure 5.--Quantities of entanglement debris and total plastics found on Middleton Island, Alaska, from 1984 to 1987. Data based on two 1-km beaches.

Table 2.--Quantities of entanglement debris and total plastics found on Amchitka and Middleton Island beaches, Alaska, 1987 (* $\underline{P} < 0.05$; ** $\underline{P} < 0.001$); n = number of 100-m sections.

	Number per 100 m	
Debris type	Amchitka n = 50	Middleton n = 18
Fishing gear		
Trawl web	5.5*	2.2
Rope	6.7	4.1
Strap	3.4	1.7
Gillnet	0.2	0.4
Gillnet floats	2.5	43.8**
Total plastics	31.0	95.0**

Table 3.--Deposition of trawl web on eight 1-km sections of beach at Yakutat, Alaska, from 1985 to 1988.

	Number of trawl web fragments deposited ashore								
	1985-1986			1986-1987			1987-1988		
Beach	Oct.-Apr.	May-Sept.	Total	Oct.-Apr.	May-Sept.	Total	Oct.-Mar.	Apr.-Sept.	Total
1	8	3	11	4	2	6	7	2	9
2	4	0	4	6	1	7	6	6	12
3	3	4	7	8	2	10	7	3	10
4	12	7	19	16	0	16	7	10	17
5	12	2	14	9	0	9	8	3	11
6	0	2	2	3	1	4	2	2	4
7	1	0	1	4	0	4	2	4	6
8	10	2	12	18	1	19	7	5	12
Total	50	20	70	68	7	75	46	35	81
Mean per kilometer per year			8.8			9.4			10.1

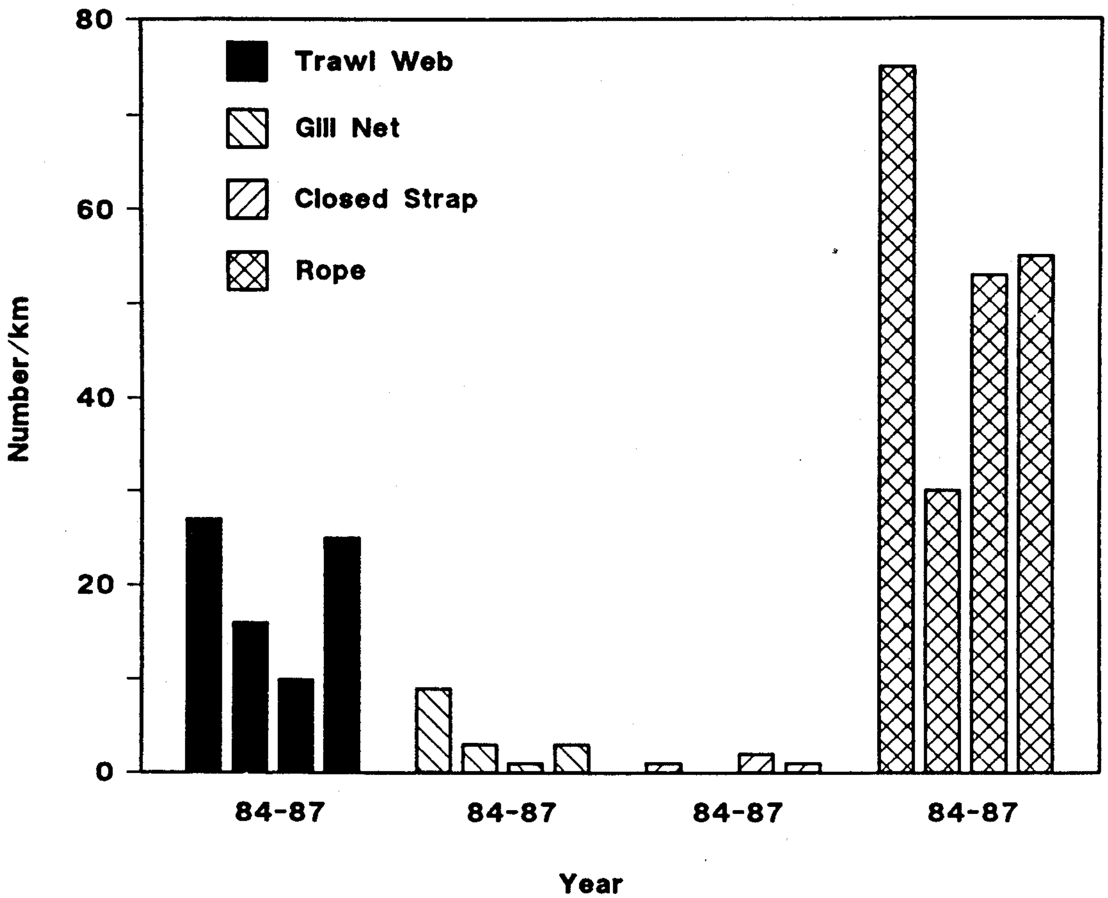

Figure 6.--Accumulation of entanglement debris on a 1-km beach on Middleton Island, Alaska, that was cleared of all debris annually from 1984 to 1987.

of surveys, knowledge of local ocean currents and prevailing winds is necessary.

Composition of plastic debris was nearly identical on Amchitka and Middleton Islands. In both locations in 1987, over 60% of the debris found on beaches was fishing gear. This does not seem unusual, considering that 5,500 km of trawl net and 170,000 km of gillnet are available to various fisheries in the North Pacific (Uchida 1985). Of the three benchmark locations, debris washing ashore on remote Amchitka and Middleton Islands is probably most representative of the types and quantities lost or discarded at sea.

With the exception of rope, which increased significantly, quantities of entanglement debris did not change significantly on Amchitka Island from 1982 to 1987. Trawl web fragments, however, did increase from 34 to 55 fragments/km, continuing the upward trend of earlier years. The average weight of a fragment of trawl web found on Amchitka Island in 1987 was 4 kg, and some of the fragments were rectangular in shape, indicating they

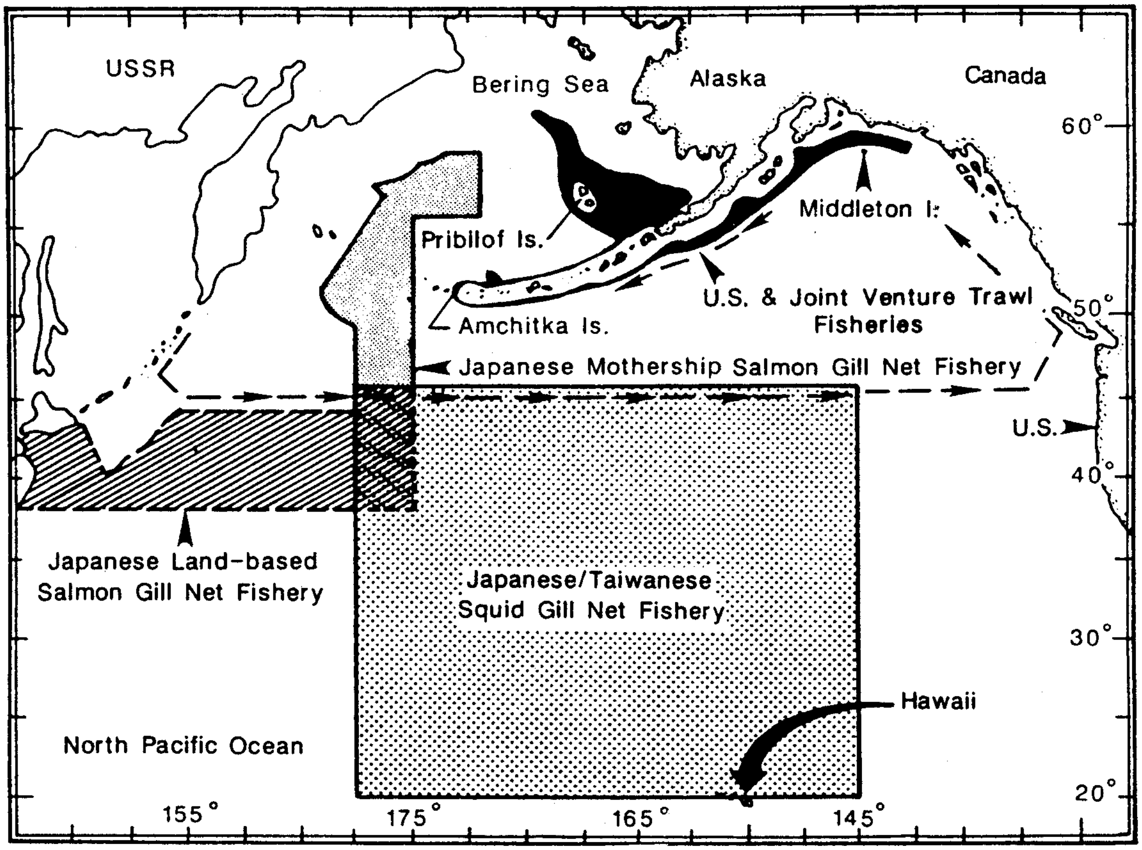

Figure 7.--Major trawl and gillnet fisheries in the North Pacific Ocean and Bering Sea. Adapted from Low et al. (1985) and Merrell (1985). Broken arrows indicate major ocean currents (Reed and Schumacher 1985).

may have been patches discarded overboard from commercial trawlers from net-mending operations. Berger and Armistead (1987) estimated that from 1982 to 1984, over 2,700 pieces of trawl web were discarded overboard into Alaskan waters from net-mending operations.

Although the number of trawl web fragments that washed ashore continued to increase on Amchitka Island, the frequency of occurrence of different mesh sizes remained stable. Approximately one-third of the fragments in both 1982 and 1987 had mesh sizes >150 mm. These are the mesh sizes most likely to entangle northern fur seals (Scordino 1985; Fowler 1987). Similar occurrences of mesh sizes have been reported for other beach locations in Alaska (Johnson 1989). Therefore, assuming trawl web washed ashore is representative of that which is floating at sea, approximately one-third of the derelict trawl web at sea could entangle fur seals.

On Middleton Island, quantities of entanglement debris remained relatively stable from 1984 through 1987, and were generally lower than quantities found on Amchitka Island. More rope and strapping and significantly

Table 4.--Mesh sizes of gillnet fragments found on Alaskan beachesfrom 1982 to 1988, and probable fishery sources (Chen 1985; Gong 1985; Uchida 1985; United States-Taiwan Bilateral Meeting 1988).

Mesh size (mm)	Number of fragments				Fishery[a]
	Amchitka Island	Middleton Island	Yakutat	Total	
55	0	1	0	1	Herring--US
95	0	1	0	1	Squid--T,K
100	0	1	0	1	Squid--T,K
105	0	1	0	1	Squid--T,K
110	0	20	7	27	Squid--T,K; Salmon--JL
115	8	7	4	19	Squid--T,K,J; Salmon--JL
120	1	4	9	14	Squid--T,J; Salmon--JM
130	0	0	1	1	Salmon--JM
Total	9	35	21	65	

[a]US = United States, T = Taiwan, K = Korea, J = Japan, JL = Japanese land-based, JM = Japanese mothership.

more trawl web were observed on Amchitka Island than on Middleton Island in 1987, probably because of the proximity of Amchitka Island to concentrated trawl fisheries in the North Pacific Ocean and Bering Sea (Fig. 7). Gill-net fragments and floats, however, were more abundant on Middleton Island than on Amchitka Island, even though Amchitka Island is closer to gillnet fisheries in the North Pacific Ocean and Bering Sea (Fig. 7). This may be due to the eastern direction (towards North America) of the subarctic ocean current (Reed and Schumacher 1985), which may transport debris from the high-seas squid and Japanese land-based salmon fisheries (Merrell 1985) into the Gulf of Alaska and favor deposition on Middleton Island.

The quantity of debris washed ashore is affected by frequency and intensity of storms, changes in ocean currents, winds, fishing effort, and areas fished. At Amchitka Island, total plastics remained at about 300 items/km in both 1982 and 1987. At Middleton Island, however, there was a 33% reduction in total plastics in 1985, possibly the result of a change in ocean currents or an unseasonable storm which may have redistributed debris from the beach. By 1986 and in 1987, debris had accumulated on beaches on Middleton Island to quantities near those observed in 1984 (~900 items/km). A decline in quantity of debris on beaches near Yakutat was also reported in 1985 (Merrell and Johnson 1987), supporting the concept that there may have been a change in ocean conditions affecting the accumulation of debris on beaches throughout Alaska. Thus, when monitoring trends in abundance, it is best to sample each beach location at the same time each year in order to document the variability between years due to changes in ocean conditions or fishing effort.

Of the entanglement debris washed ashore, the reason for the scarcity of gillnet is still unclear. Gillnet is perhaps the most likely of all gear types to be lost (Uchida 1985) but it is one of the least abundant entanglement debris items found on Alaskan beaches. Approximately 1,609,000 km (1 million mi) of gillnet are fished each year in the North Pacific Ocean, of which an estimated 965 km (600 mi) are lost or abandoned each year (Eisenbud 1985). A possible explanation for the lack of gillnets on Alaskan beaches is that they may sink to the ocean bottom from the weight of marine growths (e.g., algae, barnacles) and the carcasses of marine mammals, seabirds, and fish. In some cases, gillnets may drift at mid-depths, get stranded farther offshore in intertidal areas, and never reach the beach. Because derelict gillnets tend to collapse and "roll up" relatively quickly (Gerrodette et al. 1987), they may form a better substrate for marine growths and thereby attract fish and other predators which may get entangled, ultimately causing the net to sink. Trawl web, on the other hand, usually does not "roll up" like gillnet and does not appear to form a suitable substrate for collecting marine growths. This may explain why more trawl web washes ashore than gillnet.

The short period of time (sometimes within 1 year) in which plastic debris accumulated on a beach on Middleton Island that had been cleared of all debris suggests that a substantial amount of debris is probably adrift at sea. Johnson and Merrell (1988) reported a 40% accrual of new debris (previously unseen) on an Alaskan beach in just a 4-month period. The rapid accumulation and, often times, disappearance of debris on beaches are largely controlled by storms. Storms are primarily responsible for depositing debris ashore and removing or redistributing debris already stranded; some of the debris is washed inland to terrestrial areas or buried by sand (Johnson 1989).

Frequent sampling and tagging of trawl web fragments at Yakutat indicates that most fragments are washed ashore in the fall-winter months due to storms. Shiber (1982) also reported an increased deposition of plastic debris in winter on beaches in the Mediterranean Sea. The increase in deposition of trawl web at Yakutat from 8.8 fragments/km in 1985-86 to 10.1 fragments/km in 1987-88, is consistent with the increase in trawl web observed on beaches at Amchitka Island from 1982 to 1988. The reason for the increased deposition of trawl web on Alaskan beaches is unclear; although the number of fragments has increased, the areas fished and the total number of vessels (~300) operating off Alaska have remained relatively steady since 1978 (Low et al. 1985).

Monitoring plastic debris and derelict fishing gear on beaches in Alaska and in other locations may be the best method of evaluating whether the input of plastics into the sea is decreasing because of compliance with MARPOL Annex V. Monitoring plastic debris abundance at sea by aircraft and ship surveys may work, but isn't feasible considering the cost and the immense areas to be covered.

At present, beach surveys are an effective method to determine types, sources, and composition of plastic debris that washes ashore. Trends in abundance of plastic debris may be more difficult to determine because of the variability in the accumulation of debris in different locations and years. Therefore, a better understanding is needed of the interrelationship of ocean currents, storms, and drift patterns, and their effects on the distribution of plastic debris in the North Pacific. In addition, information is needed on the length of time plastic debris remains at sea once it is lost or discarded. Some answers may be gained by releasing marked floats at specific locations in the North Pacific Ocean and Bering Sea and following their recovery.

Regardless of limitations of beach surveys, by establishing benchmarks and continuing to sample at these locations at least once a year at approximately the same time, a trend should become evident as to whether quantities of debris are increasing, decreasing, or remaining the same. Alaskan beaches, specifically Amchitka and Middleton Islands, will serve as long-term benchmarks to monitor plastic pollution because: 1) they are remote from urban sources of pollution, 2) they continually accumulate debris, and 3) a data base of several years already exists.

In summary, plastic debris is found on many outer coast beaches throughout Alaska and most is composed of fishing gear. Rope and trawl web are the two most abundant entanglement debris items found; they continue to wash ashore in some locations in an increasing number. Monitoring debris on beaches in Alaska and elsewhere in the coastal United States for the next several years may help to determine if mitigating legislation is reducing the entry of entanglement debris and other plastics into the ocean.

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A SURVEY OF PLASTICS ON WESTERN ALEUTIAN ISLAND BEACHES AND RELATED WILDLIFE ENTANGLEMENT

Albert M. Manville II
Defenders of Wildlife and the
Entanglement Network Coalition
Washington, D.C. 20036, U.S.A.

ABSTRACT

A 10-day survey of 25 beaches (mean length of beach surveys = 149 m (162 yd)) on seven different islands (Attu, Agattu, Shemya, Buldir, Kiska, Little Kiska, and Adak) in the outer Aleutian Islands was conducted 12-20 July 1988, using the U.S. Fish and Wildlife Service's research vessel MV *Tiglax* as a base. Sites were randomly selected, and beaches were surveyed for all plastic from sea level to high storm tide level. Representative plastic samples were collected and all beaches photographed. Of the total 3.7 km (2.3 mi) of beach observed, 3,153 plastic objects were counted, representing 67 different finished plastic products. Debris was identified from Japan, the U.S.S.R., South Korea, People's Republic of China, Taiwan, Norway, and the United States. Most prevalent were items from Japan; of those that were identifiable, most were fishing related.

A precipitous decline in the Steller's sea lion, *Eumetopias jubatus*, was noted on Attu Island (77% decrease since 1979), where pinniped surveys were conducted. The results coincide with a reported 65% overall reduction in the western Aleutian Islands population of Steller's sea lions over the past 10 years. Plastics are suspected of contributing to their decline. An adult bull sea lion on Buldir Island was photographed with a strapping band and massive entanglement scar around its neck, with reports of two other entangled, scarred, but live sea lions on Kiska Island, and one on Agattu Island. Some two dozen dead seabirds were discovered during the beach surveys wrapped in plastic although exact cause of death could be ascertained for only one. The *Tiglax* was temporarily entangled in rope from an apparently active brown king crab, *Paralithodes camtschaticus*, pot.

There was a statistically significant difference in the amount of plastic found on beaches in protected coves versus that discovered on open, unprotected beaches. There was also a statistically significant difference in fishing-related versus

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non-fishing-related plastics spotted on the beaches surveyed. If the amount of plastic located on these beaches is at all indicative of that found elsewhere on Alaska's 57,924 km (36,000 mi) of shoreline, plastic debris poses a serious potential problem for fish and wildlife.

INTRODUCTION

Worldwide, plastics in the marine environment alone have been suggested to be as great a cause of mortality to marine mammals, seabirds, and sea turtles as are oil spills, pesticide poisoning, or contaminated run-off (Schneidman 1987). It is postulated that if all dumping and discarding of plastics were to stop immediately, plastics would continue to wash ashore for at least another 100 years (R. J. Wilber, Sea Education Association, Woods Hole, Mass., pers. commun.).

Reports of the presence and impacts of plastic debris in the North Pacific Ocean are fairly common in the recent scientific, popular, and governmental literature (Manville 1988). From the standpoint of origin, plastic debris can be classified as either land-based or ocean-going. Although attempts have been made to quantify at-sea plastic debris in the North Pacific and elsewhere, these attempts are difficult and yield only rough estimates. Dahlberg and Day (1985), for example, found more than 80% of the debris sighted at sea in the North Pacific to be plastic, with over 33% of this consisting of pieces of expanded polystyrene (e.g., cups, floats, boxes). Their observations were limited to floating debris, however, which does not include plastic materials denser than seawater.

Ignell and Dahlberg (1986) surveyed 7,337 km (3,960 mi) of the central and western North Pacific Ocean, and located 1,802 man-made objects adrift on the sea surface, 61 and 26% of these plastic and Styrofoam, respectively. The proportion of plastic materials they found was consistent with that found by Venrick et al. (1973), Shaw and Mapes (1979), and Dahlberg and Day (1985).

Because of the growing concerns about the aesthetic deterioration of our nation's coastline--including beaches in the North Pacific Ocean--a number of recent beach cleanup surveys have been conducted (e.g., Centaur Associates and the Center for Environmental Education (CEE) 1986), but their findings tend to emphasize floatable plastics while often excluding those plastics denser than seawater.

Ghost nets--lost or discarded nets or net fragments, especially drift gillnets--which can continue to fish for years, were reported by Manville (1988) as among the most damaging forms of plastic debris that entangle fish and wildlife in the North Pacific Ocean and elsewhere. The nets sometimes sink from the weight of dead animals, seaweed, or barnacles, and continue to catch fish on the oceans' bottoms. They also may ball up and continue to float, or wash ashore. Also reported were packing bands, six-pack yokes, nets, net fragments, and other plastics which bind and/or strangle virtually every species of marine mammal, sea turtle, seabird, many varieties of fish, and numerous invertebrates (such as lobsters and crabs).

Fowler (1982, 1987) and Fowler and Merrell (1986) reported that perhaps the best documentation of the results of entanglement in the North Pacific involves northern fur seal, *Callorhinus ursinus*. Extensive data, including the incidence of entanglement scars, were collected from 1967 through 1984 from young male seals killed in the annual commercial seal harvest on the Pribilof Islands, Alaska. These and other data indicated an alarming trend. The population is declining annually at 4-8%; its numbers are now less than half those of 30 years ago. Entanglement, particularly in trawl net fragments, plastic packing bands, and other plastic trash, is believed to be a contributing and perhaps even significant factor in the species' decline. Northern fur seals are presently listed as "depleted" under the Marine Mammal Protection Act, and were recently petitioned for listing as "threatened" under the Endangered Species Act.

While the studies by Fowler (1982, 1987) and others provide the best evidence of wildlife entanglement in plastic debris--especially northern fur seals--and while there is clear evidence that marine debris affects individuals of many species (Manville 1988), Heneman and CEE (1988) felt that evidence of serious population effects on marine wildlife is inconclusive. They cited the fact that few studies had been done on derelict nets or traps, and that while there was clear evidence that entanglement in marine debris kills or injures seabirds, there is no evidence that this is a significant problem for any seabird population. Heneman and CEE's research, however, was not conducted in the North Pacific Ocean.

The Japanese claim that the problem of lost driftnets in the North Pacific is negligible, estimating that only 0.05% of their net sets are lost per operation (the National Marine Fisheries Service estimate is 0.06% (Hinck 1986)). When applied to the setting of more than 32,985 km (20,500 mi) of net per night, plus an additional 16,090-32,180 km (10,000-20,000 mi) of driftnet from Taiwan, South Korea, and others (S. LaBudde, Earthtrust, Honolulu, Hawaii, pers. commun.), a 0.06% loss of net means at least 29-39 km (18-24 mi) of net are lost each night and some 1,542-2,058 km (959-1,279 mi) of net each season. These figures do not account for discarded nets or net fragments.

The northern (Steller's) sea lion, *Eumetopias jubatus*, was reported to have declined by about 50% in the eastern Aleutian Islands between 1957 and 1977 (Braham et al. 1980; King 1983), while western Aleutian populations were reported fairly stable or experiencing only moderate declines during that period (Early et al. 1980; Loughlin et al. 1984). Since 1977, declines continued in the eastern Aleutian Islands (Merrick et al. 1986), but no surveys had been conducted in the western Aleutians from 1979 until 1988. Results from five sites surveyed there in the mid-1970's compared with the 1988 study indicated a 65% reduction in sea lions in the western Aleutians (Byrd and Nysewander 1988). Entanglement was suggested as a possible contributing factor to declines in the eastern Aleutians (Loughlin et al. 1986), but few incidences were reported in the western islands.

Less well known is the status of seabird populations in the Aleutian Islands, and the role plastics may play in affecting these species. Commercial fishing continues to be the largest human activity in the Bering Sea. Factory ships with their fleets of catcher boats stay on location for months processing million of tons of seafood and dumping their wastes in the process (S. LaBudde, Earthtrust, Honolulu, Hawaii, pers. commun.). In Kotzebue Sound north of the Aleutians, data collected in 1977, 1981, and 1987 indicate that the horned puffin, *Fratercula corniculata*, may be experiencing a dramatic 75% decline on Chamisso Island (A. Sowls, Alaska Maritime National Wildlife Refuge, Homer, Alaska, pers. commun.). The cause of the decline is as yet unknown.

While plastic debris has been reported on the beaches of southern Alaska (Cottingham 1988), on the Pribilof and eastern Aleutian chain (Byrd 1984), and as far out in the Aleutians as Amchitka Island (Merrell 1980, 1984), no plastics beach surveys were reported in the literature from the far western Aleutian Islands prior to July 1988.

METHODS

Twenty-five beach surveys were conducted on seven outer Aleutian Islands from 12 to 20 July 1988 using the U.S. Fish and Wildlife Service's (FWS) research vessel MV *Tiglax* as a base. Surveys were undertaken on beaches in the westernmost U.S. islands located in the Near Islands group (Attu, Agattu, and Shemya Islands), Buldir Island, the Rat Islands (Kiska and Little Kiska Island), and the Andreanof Islands (Adak Island, Fig. 1). Surveys were conducted on an opportunistic basis when the *Tiglax* was either at anchor or was able to stop long enough to deploy us, and when weather and seas were sufficiently favorable to allow beach landings in a motorized, Zodiac inflatable. Beach sites to be surveyed were then randomly selected, and beaches were walked and scanned for all plastic from existing sea level to the storm high tide level/upper wrack line (Wilber 1987). Representative plastic samples were collected and all beaches were photographed. No attempt was made to assess the amounts by weight or volume of plastics present on the beaches, although the numbers of complete trawl nets and relative amounts of driftnets were noted.

Attempts were made to identify the source of plastic items by linking origin of the product, item, or piece by identifiers which were often embossed, stamped, or molded into the plastic.

Five open-water plastic surveys were conducted while the *Tiglax* was steaming between islands (Fig. 1). Surveys were conducted from either the bridge of the vessel or the flying bridge, looking for floating or drifting plastic visible from the bow of the ship while it cruised at speeds of 8-10 kn. Surveys were conducted for approximately 30-min intervals.

Particular attention was paid to wildlife entangled in plastic. Where such animals were spotted, they were photographed. Carcasses were carefully examined for external evidence of plastic or for plastic entanglement scars. Rough necropsies were conducted on dead seabirds whose crops were intact to determine if plastics had been ingested.

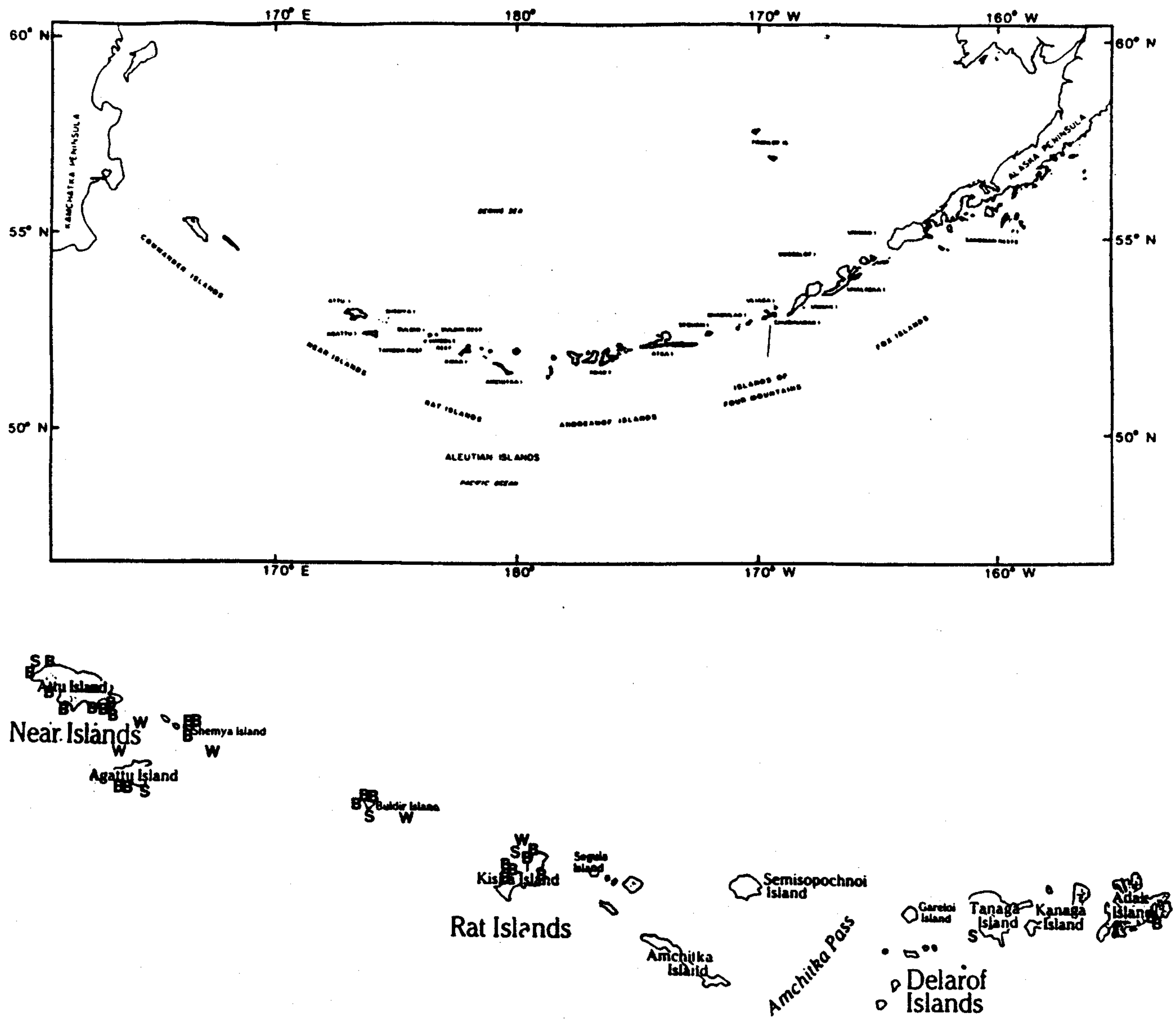

Figure 1.--Locations of 25 beach surveys conducted on 7 outer Aleutian Islands from 12 to 20 July 1988 (B), 5 Steller's sea lion surveys conducted from late June to mid-July 1988 (S), and 5 open-water plastics surveys conducted from 12 to 20 July 1988 (W). Map after Byrd and Day (1986).

Beaches were classified as protected, located in coves, bays, or harbors; or as unprotected, located on promontories, points, or similar areas facing the open ocean. In addition to the presence or absence of protective physical barriers, beach classification also was based on the likelihood of prevailing storm tracks, waves, and weather conditions which could augment accumulation of debris.

The randomization test for two independent samples (for large samples) was used to test the statistical difference in the amount of plastic found on protected beaches versus that discovered on open, unprotected beaches (Siegel 1956). This test was also used to examine the difference between fishing-related and nonfishing-related plastics located on the beaches. Fishing-related debris consisted of material specifically used for fishing, material used in the packaging of fish and fish products, or material used by fishermen during the capture and processing of fish.

Northern sea lion counts were conducted either from land or at sea between approximately 1000 and 1800 on five islands during late June and early July (Fig. 1). This enabled peak bull, cow, and pup counts (Loughlin et al. 1986; Byrd and Nysewander 1988). When counts were made on land within the rookeries, numbers of sea lions were assessed "using spook counts" where one or two researchers drove bulls and cows into the water to facilitate counting the pups still on land. All animals were carefully assessed for signs of entanglement using binoculars and a telephoto-equipped 35-mm camera. Where haul sites and rookeries could be seen from headlands above, such as on Kiska Island, counts were made from land by one researcher using binoculars. Where counts were made from the water, three or four observers stationed 30-75 m (33-82 yd) offshore in a Zodiac inflatable counted all pinnipeds. Where counts were made by more than one observer, replicated tallies were averaged to provide the most representative value for each site. Counts were conducted on Attu, Agattu, Buldir, Kiska, and Gramp Rocks. Counts made in 1988 were compared with those made in 1977 (Day et al. 1978) and 1979 (Early et al. 1980).

RESULTS AND DISCUSSION

Beach Surveys

Twenty-five beach surveys were conducted on seven outer Aleutian Islands from 12 to 20 July 1988. Beach surveys averaged 148 m (162 yd) in length. On the 3.7 km (2.3 mi) of beach observed, 3,153 plastic objects were discovered, representing 67 different finished plastic items. No raw polyethylene pellets (nibs), or spheres or spherules of polystyrene were discovered, although due to time limitations attempts were not made to look carefully for them in the high wrack lines. On the average, 126 different plastic items were found per survey. All beaches examined, including the most protected, contained plastic; at least 15 items were deposited on the cleanest (a protected cove on the south side of Shemya Island).

Most prevalent of the plastic items found on the beaches were rope, Styrofoam driftnet buoys, fishing net (mostly trawl nets, but some driftnet segments), and bottles (Table 1). Like the beaches of Bermuda and the

Table 1.--Types and incidence of plastics found on 25 beaches of 7 islands in the outer Aleutian Islands, Alaska, July 1988.

No.	Plastic item	Count	No. of beaches with item	Type[a]
1	Rope (piece, complete coil)	706	24	F
2	Styrofoam buoy	535	15	F
3	Fishing net (mostly trawl)	360	24	F
4	Bottle (other plastic)	331	21	N
5	Hard plastic buoy	215	17	F
6	Plastic piece	157	15	N
7	Piece of Styrofoam	148	23	F/N
8	Cap and lid	111	17	N
9	Strapping band	102	21	F/N
10	Fish-sorting basket	61	12	F
11	Bottle (green plastic)	55	15	N
12	Japanese beer crate	49	8	N
13	Bag	35	15	N
14	Shoe	27	10	N
15	Cup, spoon, fork, plate	23	12	N
16	Sheeting (large plastic)	19	11	F/N
17	Sheeting (small plastic)	18	9	F/N
18	Tub	16	2	N
19	Milk jug	15	9	N
20	Jug	14	5	N
21	Glove	12	8	F/N
22	Bucket	11	9	F/N
23	Polyvinyl chloride pipe	11	7	N
24	Soda bottle	9	8	N
25	Monofilament fishing line	9	4	F
26	Hard hat	7	4	F/N
27	Packaging	7	1	N
28	Styrofoam fast food container	6	4	N
29	Insulation for cable	6	3	N
30	Disposable lighter	5	2	N
31	Styrofoam egg carton	4	3	N
32	Styrofoam cup	4	2	N
33	Cable liner	4	2	N
34	Reflector	4	2	N
35	Boot (with plastic parts)	4	1	F/N
36	Brush	3	3	N
37	Six-pack holder	3	3	N
38	Styrofoam cooler	3	2	F/N
39	Insulation	3	2	N
40	Slipper	3	2	N
41	Toy	3	2	N
42	Drift card[b]	3	1	N
43	Container top	3	1	N
44	Gas can	2	2	F/N
45	Styrofoam life ring	2	2	F/N

Table 1.--Continued.

No.	Plastic item	Count	No. of beaches with item	Type[a]
46	Electrical tape	2	2	N
47	Pen	2	1	N
48	Tooth brush	2	1	N
49	Bowl	1	1	N
50	Indoor-outdoor carpet	1	1	N
51	Caulking tube	1	1	N
52	Counter top	1	1	N
53	Dishwasher sprayer	1	1	N
54	Electrical fixture	1	1	N
55	Filter	1	1	N
56	Garbage can lid	1	1	F/N
57	Ice tray	1	1	N
58	Mylar food pouch	1	1	N
59	U.S. Navy sonabuoy container	1	1	N
60	Plug	1	1	N
61	Pump	1	1	N
62	Ring	1	1	N
63	Shower curtain	1	1	N
64	Soap dish	1	1	N
65	Thermos top	1	1	N
66	Trash can	1	1	F/N
67	Watering jug for plants	1	1	N
	Subtotal	3,153		
1	Crab buoy attached to rope[c]	2	--	F
2	Piece of floating Styrofoam[c]	4	--	F/N
	Subtotal[c]	6		
	Grand total	3,159		F - 7 N - 48 F/N - 13

[a]F indicates item is fishing-related; N indicates that it is non-fishing-related; F/N indicates that it is both.

[b]National Marine Fisheries Service drift card.

[c]Items discovered during open-ocean survey while departing north end of Kiska Island, 19 July 1988.

Bahamas, which are heavily littered with plastic delivered from a large Atlantic Ocean circulation pattern known as the central gyre (Wilber 1987), the Aleutian Islands act as "sieves" for plastics circulated by waters from the Japanese and Bering Sea currents. Nevertheless, if the amount of plastic located on these Aleutian Island beaches is indicative of that found elsewhere on Alaska's 57,924 km (36,000 mi) of shoreline, there is tremendous opportunity for entanglement or ingestion by wildlife.

Litter was identified from Japan, the U.S.S.R., South Korea, the People's Republic of China, Taiwan, Norway, and the United States, although most of the plastic could not be specifically related to country of origin. Most prevalent were items from Japan; those identifiable were mostly fishing related.

There was a statistically significant difference in the amount of plastic found on protected beaches versus that discovered on unprotected beaches ($P < 0.001$, df = 23, 22,502; Table 2). There also was a statistically significant difference in the amount of fishing-related versus non-fishing-related plastics located on beaches examined ($P < 0.001$, df = 24, 14,083; Table 1).

Although beaches varied considerably in composition, ranging from sandy to pebbly to rocky to boulder-covered, accumulations of plastic litter were not consistently different among the beaches (Table 2). These findings were consistent with those reported by Merrell (1980, 1984).

When comparing the total amount of plastic (N = 2,457 items) versus Styrofoam (N = 696 items) found on the 25 beaches, non-Styrofoam plastic made up 78% of the waste stream while Styrofoam consisted of about 22%.

Of particular interest was the discovery of a six-pack beverage yoke on each of three remote beaches (Table 2), since I had been asked to look for and testify about them before a joint congressional hearing held after my return to Washington, D.C., on 26 July (U.S. Government Printing Office (GPO) 1988). One of these yokes was a Hi Cone Eco photodegradable beverage ring (manufactured by Illinois Tool Works), which had not then begun to show any signs of embrittlement.

Open Water Surveys

Five open-water plastic surveys were conducted while the *Tiglax* was underway between islands. One open-water survey on 19 July off the north end of Kiska Island produced two buoys from a brown king crab, *Paralithodes camtschaticus*, pot, one rope from the pot, and four pieces of floating Styrofoam over an 8 km (5 mi) course (Table 1). Even the *Tiglax* was not immune to entanglement plastics. Her hull became ensnared in the rope from an apparently active brown king crab fishing set.

Dead Seabirds

During the 25 beach surveys, some two dozen dead seabirds were located wrapped in, lying next to, or partially entangled in plastic debris,

Table 2.--Amounts of plastic found on 9 protected and 16 unprotected beaches of 7 islands in the outer Aleutian Islands, Alaska, July 1988.

No.	Beach location[a]	No. of plastic items discovered[b]
	Protected	
1	South Side Beach, Shemya Island	15 (s)
2	Scotts Cove, southwest side, Shemya Island	34 (s)
3	Casco Bay, Inlet Beach, southwest side, Attu Island	19 (r)
4	Casco Bay, small subbay, southeast side, Attu Island	18 (s)
5	Casco Bay, small subbay, southeast side, Attu Island	22 (p/r)
6	Casco Bay, another subbay, Attu Island	19 (s/r)
7	Alcan Harbor, northwest boat dock, Shemya Island	37 (r)
8	Sweeper Cove, Adak Harbor, Adak Island	22 (b)
9	Sweeper Cove, Adak Harbor, Adak Island	21 (b)
	Unprotected	
1	Temnac Beach, south side inlet, Attu Island	37 (s/p)
2	Etienne Cove, southwest side, Attu Island	184 (s)
3	Wrangell Beach, Wrangell Point, Attu Island	511 (p/r)
4	Earle Cove, north side, Attu Island	45 (s/p)
5	Karab Cove, south central, Agattu Island	286 (p)
6	Karab Cove, south central, Agattu Island	48 (s/p)
7	North Bight Beach, near base camp, Buldir Island	329 (r)
8	North Bight Beach, sea lion rookery, Buldir Island	63 (r)
9	North Bight Beach, near base camp, Buldir Island	235 (r)
10	Dark Cove, Kiska Island	284 (s/r)
11	Dark Cove, Kiska Island	379 (s/r)
12	Rock beach, north side, Little Kiska Island	64 (r/b)
13	Three-Mile Beach, Kiska Island	31 (b)
14	Three-Mile Beach, Kiska Island	113 (b/s)
15	Three-Mile Beach, Kiska Island	174 (b/s)
16	North Three-Mile Beach, Kiska Island	170 (b)

[a]Beaches designated as protected were located in coves, harbors, or bays, while those designated as unprotected were located on points, promontories, or areas subject to direct wave action from the open ocean, prevailing storm tracks, and weather conditions which likely augmented the accumulation of debris.

[b]b - boulder beach, p - pebble beach, r - rock beach, s - sand beach.

[c]A six-pack beverage yoke was discovered on each of these three beaches, but at Karab Cove, Agattu Island, the yoke was a Hi Cone Eco photodegradable carrier.

including trawl nets, a piece of driftnet, and plastic rope. With the exception of one dead sooty shearwater, *Puffinus griseus*, wrapped in a piece of trawl net that appeared to strangle it, it usually was impossible to determine the cause of death, given the decomposition of the majority of the carcasses. A Leach's storm petrel, *Oceanodroma leucorhoa*, however, was discovered in August 1988 on Buldir Island entangled in monofilament fishing line which apparently killed the bird (G. V. Byrd, Alaska Maritime National Wildlife Refuge, U.S. Fish and Wildlife Service, Nome, pers. commun.).

Field necropsies revealed no ingested plastics in the few birds (a tufted puffin, *Lunda cirrhata*, two glaucous-winged gulls, *Larus glaucescens*, a sooty shearwater, two crested auklets, *Aethia cristatella*, a least auklet, *A. pusilla*, and a common murre, *Uria aalge*, whose crops were intact. More research on seabird mortality needs to be conducted in the outer Aleutian Islands. Plastics are of special concern since seabirds tend to concentrate in areas where current upwellings reach the surface or where tidal rips occur (J. F. Piatt, Alaska Fish and Wildlife Research Center, FWS, Anchorage, Alaska, pers. commun.)--the same areas where ghost nets, drifting plastic debris, and other flotsam may also occur. Although the impacts of lost or discarded fishing gear and other plastic debris have been difficult to quantify, the few data available suggest that lost gear may be as efficient at killing birds and mammals as is active gear (DeGange and Newby 1980; Jones and Ferrero 1985; Piatt and Nettleship 1987).

Northern Sea Lion Counts

Attu Island

Although counts were made for northern (Steller's) sea lions on 8 and 14 July, the second count was made at a more appropriate hour and therefore was considered more representative. A comparison of this 1988 count with the one made in 1979 (Early et al. 1980), shows a precipitous 77% decline from about 5,700 animals to approximately 1,300 (Byrd and Nysewander 1988). Cause of the decline is unknown.

Agattu Island

Counts were made in mid-June when harem bulls were at their peak and on 9-11 July after most pups were born. The estimated 1988 count of 3,000 sea lions was less than half the number counted in 1979 (Byrd and Nysewander 1988). One bull was seen with a piece of trawl net fragment wrapped around its neck.

Buldir Island

Twenty-two areas were identified for sea lion surveys at Buldir Island, and June and July counts were made for most of these sites. Less than 1,900 sea lions were counted in 1988, 70% fewer than the 1979 survey (Byrd and Nysewander 1988). I photographed a harem bull with a massive entanglement scar around its neck and the strapping band apparently still present. The animal appeared robust and generally healthy, and maintained a territory with one cow (but no pups) several hundred meters west of the Bull Point Beach sea lion rookery.

Kiska Island

Earlier single counts on Kiska and Tanadak Islands were followed by a mid-July count from land. The overall total for Kiska and Tanadak Islands in 1988 was 2,414 sea lions, a 64% decline from the total seen in 1979 (Byrd and Nysewander 1988). A bull and a cow were seen with deep scars around their necks from previous apparent plastic entanglement.

Gramp Rocks

In 1977, Day et al. (1978) reported sighting over 2,200 sea lions on Gramp Rocks. In late June 1988, over 900 pinnipeds were observed from land, representing a 59% decrease in the population.

Although it was certainly possible that some entangled sea lions were overlooked, those observed represented only a tiny fraction of total population examined. Sea lion populations have declined, probably drastically, in the western Aleutian Islands in the past decade--an overall 65% reduction for the five sites examined--but the reasons for this decline remain unclear. Entanglement has been suggested as a possible contributing factor, especially in the eastern Aleutian Islands (Loughlin et al. 1986; Byrd and Nysewander 1988), but it needs much closer examination in the western Aleutians.

Since pups and juvenile sea lions, like their northern fur seal counterparts, are curious, inquisitive, and playful (King 1983), they may suffer much higher mortality due to entanglement in plastic fishing debris than observed. Since so little research has been done on the sea lions in the western Aleutians, mortality due to plastic entanglement--although suspected by this author to be a contributing factor to their decline--needs more detailed study and analysis.

Presentation of Survey Data at Congressional Hearing

Using data from this study, information was presented at a joint congressional hearing on six-pack yoke legislation on 26 July 1988 (U.S. GPO 1988). Those bills, H.R. 5117 and S. 1986, requiring that six-pack beverage yokes be made degradable within 24 months, were passed by Congress and signed into law late in 1988 by President Reagan.

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ENTRAPMENT OF SEA-DEPOSITED PLASTIC ON THE SHORE OF A GULF OF MAINE ISLAND

Richard H. Podolsky
Research and Academics
Island Institute
60 Ocean Street
Rockland, Maine 04841, U.S.A.

ABSTRACT

During 1987, 300 kg of sea-deposited plastic debris were collected and removed from the 14.45-km shoreline along a wilderness island in eastern Maine. Exactly 1 year later, 124 kg of plastic were collected along the same shoreline. The plastic debris was not uniformly distributed among shoreline habitats. Beach, boulder, marsh, and meadow shorelines were found to catch plastic debris, and ledge shores were found to repel plastic. The western half of the island, facing the prevailing wind, had twice the plastic accumulation of the eastern half.

In R. S. Shomura and M. L. Godfrey (editors), Proceedings of the Second International Conference on Marine Debris, 2-7 April 1989, Honolulu, Hawaii. U.S. Dep. Commer., NOAA Tech. Memo. NMFS, NOAA-TM-NMFS-SWFSC-154. 1990.

WASHUPS OF FLOATABLE WASTE MATERIALS AND THEIR IMPACT ON NEW YORK BIGHT BEACHES

R. Lawrence Swanson and Robert Zimmer
Waste Management Institute
Marine Sciences Research Center
State University of New York
Stony Brook, New York 11794, U.S.A.

ABSTRACT*

During the summers of 1987 and 1988, the New York Bight once again experienced a series of incidents in which waterborne, floatable, waste materials and debris were stranded on area beaches. Medically-related wastes were of particular concern. The sources of floatable wastes are identified and local climatological data are used to explain the process by which floatable material was transported.

The climatology of the summers of 1987 and 1988 are compared with that of 1976, when similar strandings of floatable wastes occurred on the south shore of Long Island. The summer wind records of these years are also compared with the historical wind record, 1959-1988. The basis of these comparisons are measures of wind persistence and relative energy. These analyses indicate the unusual nature of the conditions that prevailed in 1976, 1987 and 1988 and how they differed from each other. During unusually persistent winds, floatable debris in near surface waters can be transported in excess of 100 km in a direction opposed to the general flow over the continental shelf. While major washups of floatable wastes are unusual, we now know under what conditions they are likely to occur. Emphasis must be placed on alleviating the problem at the sources.

*Abstract from "Meteorological conditions leading to the 1987 and 1988 washups of floatable wastes on New York and New Jersey beaches and comparison of these conditions with the historical record." *Estuarine, Coastal and Shelf Science* (1990) 30:59-78. Academic Press Limited. London. By permission.

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PLASTIC DEBRIS AND DERELICT FISHING GEAR ON SHACKLEFORD BANKS, NORTH CAROLINA

K. V. Koski
Alaska Fisheries Science Center Auke Bay Laboratory
National Marine Fisheries Service, NOAA
Auke Bay, Alaska 99821, U.S.A.

ABSTRACT

Surveys of the quantity, type, and source of plastic debris on beaches on Shackleford Banks, Cape Lookout National Seashore, North Carolina, were conducted in December 1986 and September 1987 by the National Marine Fisheries Service Beaufort Laboratory and the National Park Service. Eight 1-km beaches established as benchmarks were surveyed and measured using standard beach survey methods developed in Alaska. In 1986 an average 863 items/km of beach were found. Packaging industry items comprised 51%; fishing gear (commercial and sport), 15%; fragments, 14%; maritime industry, 8%; miscellaneous, 7%; and personal effects, 5% of the total debris. Fourteen percent of the debris items were categorized as entanglement dangers, and 55% were categorized as ingestible dangers to marine animals such as the endangered marine turtles: Fishing gear contributed significantly to the entanglement items and packaging contributed significantly to the ingestible items.

In 1987, an average of 1,073 items/km of beach were found, an increase of 25% from 1986. Four transects of beach cleared of all debris in 1986 and resurveyed in 1987 increased 117% from 526 items/km to 1,141 items/km. Composition was similar to that found in 1986. Shackleford Banks ranks high in the amount of plastic debris on its beaches when compared to beaches in Texas, Oregon, and Alaska. Because several species of endangered marine turtles utilize the barrier islands of the southeast United States for nesting, plastic debris may pose a serious threat to their well-being.

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ANTHROPOGENIC AND NATURAL DEBRIS ON A SOUTH TEXAS BARRIER ISLAND BEACH

Anthony F. Amos and Pamela T. Plotkin
Marine Science Institute
University of Texas at Austin
Port Aransas, Texas 78373, U.S.A.

ABSTRACT

The results of a long-term study to estimate the quantity of both natural and man-made debris that washed up on the gulf beach of Mustang Island, Texas, are presented. The study beach is 12 km long and has been monitored since 1978 with over 1,800 observations and 4,000 man-hours of observational effort. Four types of debris measurements are made: (1) estimates of 40 different categories of debris and litter using a ranking system (done bi-daily since 1983); (2) counts of some 70 categories of debris items (done weekly since early 1987); (3) quantity (weight) and quality of all debris at three 10-m-wide beach transects (done weekly for 1 year in 1987); (4) counts of four key anthropogenic litter items thought to be typical of four separate sources (done bi-daily for the past year). Method 1 shows seasonal tendencies but is not precise enough to indicate longer term trends. Method 2 gives much more accurate quantitative data but still reveals no trends over the 2-year period. Method 3 reveals associations of anthropogenic and natural material, quantifies "uncountable" items like tar balls, and allows examination of the world of "microtrash." Method 4 shows the short- and long-term variability of litter associated with commercial fishing and offshore oil activities, and material from south of the United States-Mexico border.

Some results of the study to date:

- There is a seasonal variation in quantity of most beach debris--highs in spring and autumn, lows in summer and especially winter.

- Most anthropogenic litter comes from offshore and is identifiable with commercial fishing, recreational boating, offshore drilling and production, and the international merchant marine (items from 60 countries have been found here).

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- Short-term variability is large and is attributable to winds, storms, tides, currents, beachgoing, and beach cleaning activities.

- Despite this variability, anthropogenic debris is a permanent feature of this beach's flotsam and jetsam. Some high counts: Styrofoam 1,100/km, plastic bags 1,000/km, plastics of all kinds 1,600/km, 1-gal (3.785 L) milk jugs 50/km, laughing gull 500/km and sanderling 150/km (the two dominant bird species), Portuguese man-of-war 1,200/km, people 25/km. Some high numbers by weight: Sargassum 2,600, tar balls 2,100, driftwood 1,000, plastic debris 140 kg/km.

SOLID WASTE ON THE ISRAELI COAST--COMPOSITION, SOURCES, AND MANAGEMENT

Abraham Golik and Yaron Gertner
National Institute of Oceanography
Israel Oceanographic and Limnological Research
Haifa 31080, Israel

ABSTRACT

Counts of litter pieces of six Mediterranean Sea beaches in Israel were conducted at monthly intervals between May 1988 and January 1989. Litter consisted of 71.6% plastic items, 7.9% wood, 5.7% metal pieces, 3.1% glass, and 11.7% other. Most of the litter, such as beverage bottles, food containers, cosmetics remnants, plastic bags, pieces of garments, and foam rubber mattresses, is related to recreation activity and is therefore land-based garbage. The absence of fishing gear remnants and large food packaging material indicative of ships' garbage, and the sparseness of litter with inscriptions and imprints showing foreign origin, further support the conclusion that most of this garbage is land-based.

This finding contrasts those of similar studies which were carried out on other coasts around the world such as Amchitka Island, Alaska; Helgoland Island, Germany; and the west European shores. There, most rubbish consisted of fishing gear, lavatory cleansers, household cleaners, and containers bearing inscriptions indicative of foreign origin, and is marine-based. The difference in the litter reflects the differences between Israel and the mentioned locations in coastal use, ship traffic, and winds, waves, currents, and tide conditions.

The significance of identifying the litter source is that mitigation of this problem in Israel is rather simple because it is easier to control land-based litter than sea-based. There are indications that proper publicity, education, and control will reduce the problem.

INTRODUCTION

During the last two or three decades, there has been growing concern about marine pollution by persistent litter. Most of the reports on this subject deal with litter in the oceans and only a few with coastal litter. Some reports, such as those of Carpenter et al. (1972), Gregory (1977,

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1983), and Shiber (1979, 1987), provided qualitative and quantitative information on coastal garbage; others showed the deleterious effect of the coastal rubbish on seals (Merrell 1980) and seabirds (Schrey and Vauk (1987); and others investigated the sources and fate of the coastal litter (Dixon and Cooke 1977; Merrell 1980; Dixon and Dixon 1981; Vauk and Schrey 1987).

Due to the temperate climate of the Mediterranean Sea and the large number of sunshine hours, its surrounding countries are presently undergoing an intensive development of coastal-oriented tourism. Although coastal pollution is one of the deterrents to tourism, tourism may be important as a contributor of waste to the beaches. Very little information is available on litter pollution of the Mediterranean Sea and its coasts. Shiber (1979, 1982, 1987) reported on the occurrence of plastic beads on the beaches of Lebanon and Spain, Saydam et al. (1985) on floating garbage off Turkey, and Morris (1980) and McCoy (1988) on litter floating in the east Mediterranean.

The gravity of solid waste as a marine and coastal pollutant was recognized by the Convention for the Protection of the Mediterranean Sea Against Pollution (Barcelona Convention) which, in one of its protocols, prohibits the dumping into the Mediterranean Sea Area of (among others) ". . .persistent plastic and other persistent materials. . . ." In order to evaluate the magnitude of this pollutant in the Mediterranean Sea, the United Nations Environmental Programme has set up a program to monitor solid and persistent litter in the Mediterranean Sea and on some of its coasts. This report is a partial result of that effort.

THE ISRAELI COASTLINE

The Mediterranean coastline of Israel extends for 200 km from the Egyptian border in the south to Akhziv on the Lebanese border in the north (Fig. 1). It is a smooth, slightly curving coastline, with Haifa Bay being the only large indentation in it, and may be divided into two sections. The southern section, from the Egyptian border to Akko, consists of long beaches, 30-50 m wide, covered by fine to medium quartz sand. The northern part, from Akko to the Lebanese border, is mostly a rocky coastline with pocket beaches which are covered by coarse, biogenic sand.

During the winter, alternating high and low barometric pressures cross the east Mediterranean Sea from west to east, subjecting the Israeli shoreline to storms at about a 10-day frequency. During the storms, winds blow from the west and southwest. Before and after the storms, wind direction is generally from the east. During spring and autumn, winds are commonly from the east (land), and during summer, the sea breeze changes from a maximum of 18-20 km/h shoreward at noon to no wind at night and about 6 km/h seaward early in the morning. The mean significant wave height during the winter is 1.1 m, during spring and autumn 0.5 m, and in the summer 0.7 m. The alongshore current during the winter storms is from south to north; whereas during the summer it is mostly from north to south in the study area. Tidal range is approximately 30 cm, and tidal currents are insignificant.

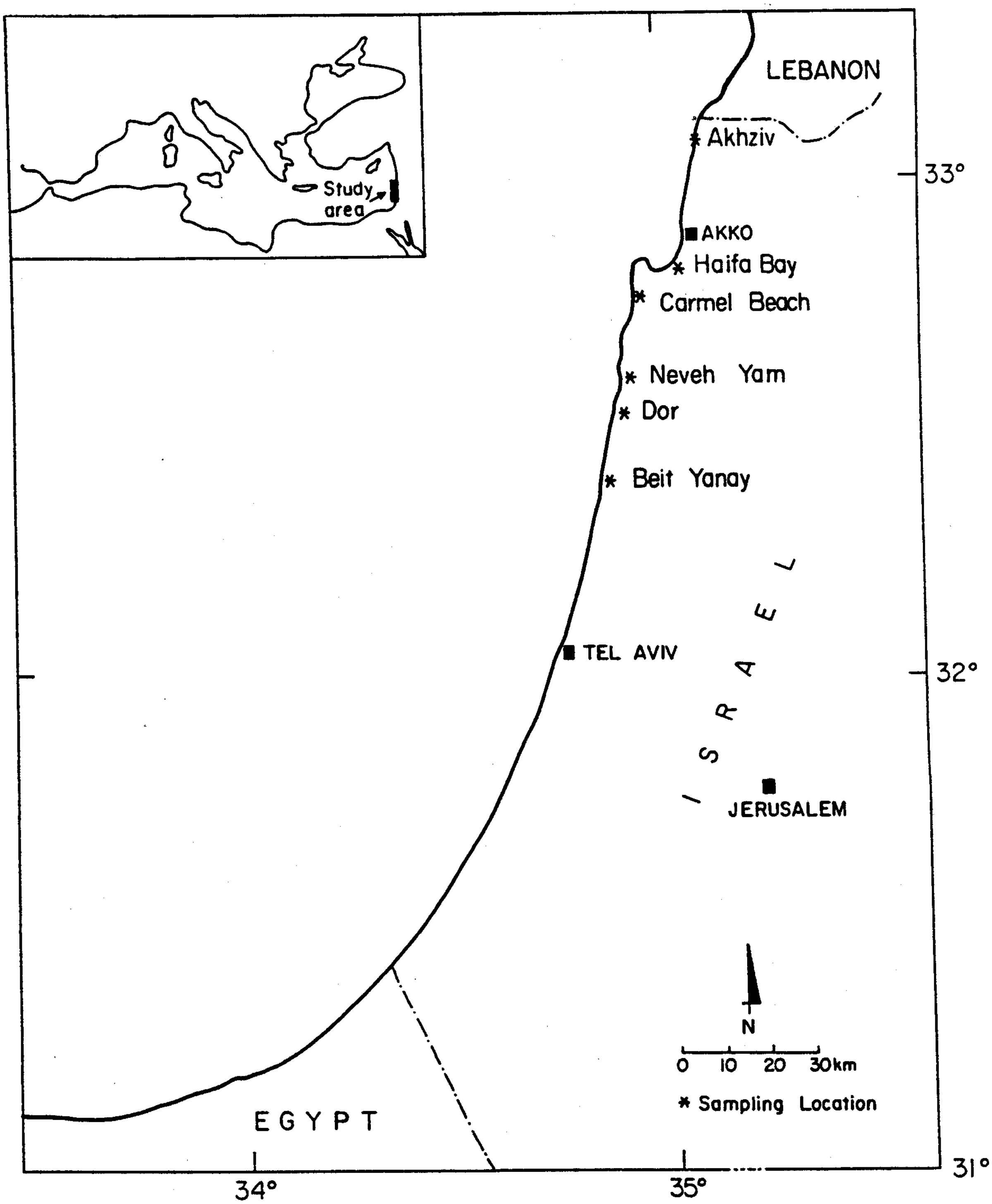

Figure 1.--Station location map.

Some 70 beaches, declared as public swimming beaches, are present on the Israeli coastline. "Declared" beaches are operated by the various municipalities, which are responsible, among other things, for keeping these beaches clean during the swimming season. Though most of the bathers go to declared beaches, undeclared beaches are popular too and are visited by many during the summer. Once or twice a year, the Office of Environmental Quality, together with local councils, conducts a cleanup of almost the entire shoreline of Israel.

The purposes of this study were to evaluate the quantity of the coastal litter on the Israeli coastline, to find out if there is any relationship between beach morphology or beach use and litter, to determine whether the rubbish is land-based or sea-based, and to recommend means and ways to treat this problem.

METHODS

Six beaches were selected for this study. They differ in their morphology, sedimentology, and type of use; their locations are given in Figure 1.

On each beach five to eight transects were established. The locations of transects were randomly determined at each sampling date. The transect was 5 m wide, oriented normal to the beach, from the water line to the back of the beach. The back of the beach was determined as the foot of the coastal cliff, the dunes, or the vegetated area. All litter pieces larger than 2 cm found on a transect constituted a sample. Sampling started in May 1988 and continued until January 1989 at roughly monthly intervals, yielding 330 samples.

RESULTS

Because the sampling program still continues as these lines are written, the distribution of litter in space and time will be discussed in the future. Only litter composition is treated here.

The relative abundance of the various litter constituents and the types of materials identified are summarized in Figure 2 and Table 1. The most abundant components are plastic fragments. Most of these are hard plastic ranging in size from 2 cm (the smallest size counted) to 30 cm, and in most cases they could be identified as fragments of plastic containers or bottles. There were also a few straps from large packing crates. Although no special count was made, most of the plastic containers and bottles originally contained beverages, food, and cosmetics (mostly suntan lotion). Only a small fraction of the plastic containers were cleansers or various types of oil related to household or industrial activities. Plastic and metal caps were counted separately, but they came from the plastic containers and bottles and were included under the plastic category. Most of the metal components were tins used for beverages; the rest were either food cans or aerosols. In a similar way the glass fraction was dominated by soft drink bottles, with low numbers of other items such as light bulbs. The wood category included driftwood as well as crate fragments.

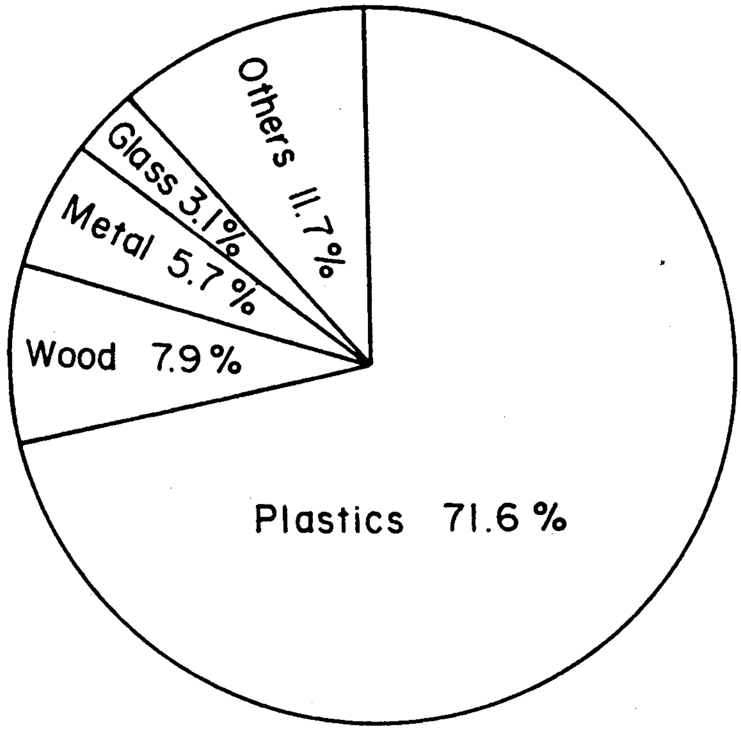

Figure 2.--Relative abundance of litter components.

Items of foreign origin (as indicated by inscription or imprinting) were found in low numbers. Most of these were from Lebanon but a few items with Turkish, Greek, and Spanish inscriptions were found as well. Although items were found at most of our sampling stations, the one in Akhziv, close to the border of Lebanon, contained the most.

DISCUSSION

Rubbish Composition and Sources

Examination of the litter components shows that most of the garbage on the Israeli coastline results from beach recreation activity. This is indicated by the original contents of most of the containers, bottles, and cans (beverages, food, and cosmetics), by the plastic bags used by beachgoers to carry their food and other belongings, by fragments of Styrofoam floats for children who go into the water, by remnants of rubber foam mattresses for lying on the beach, and by the various garment pieces, such as rubber sandals, which are good indicators of beachgoers. Mixed with this, and represented in smaller quantities, is garbage that originated from other sources. This fraction is represented by wood, rope, miscellaneous bottles and containers, and plastic and metal straps.

The absence of fishing gear remnants and packaging material of food in bulk, characteristic of ship litter, is considered to be evidence that most of the coastal litter is land-based. The paucity of foreign garbage pieces

Table 1.--Total litter in sampling stations during study period.

Material	Number of items		Percentage	
Plastic				
Fragments	3,634		31.9	
Bags	2,322		20.4	
Containers and bottles	1,076		9.5	
Caps and covers	1,069		9.4	
Other	40		0.4	
Subtotal		8,141		71.6
Wood		904		7.9
Metal				
Cans	498		4.4	
Containers	90		0.8	
Aerosols	66		0.6	
Subtotal		654		5.8
Glass				
Bottles	308		2.7	
Other	51		0.4	
Subtotal		359		3.1
Other				
Cartons	358		3.1	
Ropes	319		2.8	
Styrofoam	292		2.6	
Garments	234		2.0	
Foam rubber	105		0.9	
Subtotal		1,311		11.4
Total		11,366		99.8

is further evidence of this. Foreign litter on Akhziv beach is a result of the alongshore current which flows during summer mostly from the north and carries the garbage from Lebanon to Israel, thus impacting the northern beaches of Israel. Had it been ships' litter, the whole coastline would have been affected.

Comparison With Litter From Other Coastlines

Merrell (1980, 1984, 1985), who studied the coastal litter in Amchitka Island, Alaska, between 1972 and 1982, found that out of the 24 most common litter items, 12 were used in commercial fishing. In 1974, these constituted 65% by counts, and in 1982, 34%. Merrell attributes the rest of the litter to garbage which was discarded from the fishing fleets in the Pacific Ocean. Vauk and Schrey (1987), who investigated litter on the beach of Helgoland Island in the German Bight, reported that 99.2% of the 8,539 waste items found on the beach were identifiable as ships' waste.

Dixon and Dixon (1981, 1983) report on a series of coastal litter surveys which were conducted in the United Kingdom; the Western Isles of Scotland; Cherbourg Peninsula, France; West Jutland, Denmark; and Portugal. In all instances they noted that the most abundant plastic containers found were for lavatory and household cleaners. Plastic and carton containers for milk were also abundant, but their relative abundance was not the same on all of these coasts. Bottles of mineral water, wine, and soft drinks were found in small percentages. The geographical origins of the containers indicated that many were from countries foreign to the beach on which they were found. In short, most of the litter stranded on the beaches of western Europe is seaborne and has not been brought by people coming for recreational purposes.

The difference between the coastal litter found on the Israeli shore and litter items described above is clear--most of the waste in Israel is of local origin and is related to beach recreation activity, whereas a major proportion of the discussed examples is foreign and related to commercial fisheries and ship traffic. The reasons for this difference are clear. For the islands of Amchitka and Helgoland, the litter production by local inhabitants is negligible in comparison to that which lands from the sea. On western European shores, intensive ship traffic and commercial fisheries produce much marine-based litter which is spread widely by the strong winds, currents, and tide. The input of land-based litter by beachgoers, on the other hand, is rather limited due to the short summer recreation period in these countries. The situation in Israel is the opposite. The summer beach recreation period is long (April-November), ship traffic in the east Mediterranean is much lighter than in the North Sea, the English Channel, and the eastern Atlantic, and winds and currents which may bring garbage from the sea are moderate (see above).

Mitigation of Coastal Litter in Israel

The significance of the findings of this study is that the control of solid waste on the Israeli shore is less of a problem than it is on many other coastlines. Most students of coastal and marine litter problems admit that there is little hope of controlling disposal of garbage from ships in the near future (Dixon and Dixon 1981; Bean 1987). As this source of garbage is limited in the case of the Israeli coastline, the attention there should be focused on those who pollute the beach, namely the beachgoers. This is a matter of culture, and has to be treated with the classical tools of education, legislation, and law enforcement. Indeed various programs to educate bathers to keep the beach clean are under way. Plastic refuse bags are distributed to beachgoers by youngsters, and classes of young students are called for voluntary beach cleaning operations. The idea is that these activities will not only help to clean beaches but will also educate children to keep them so in the future. There are signs that this approach will be successful. Figure 3 shows a plastic bag which was filled with garbage by beachgoers who were conscientious not to leave their refuse spread on the beach. However, due

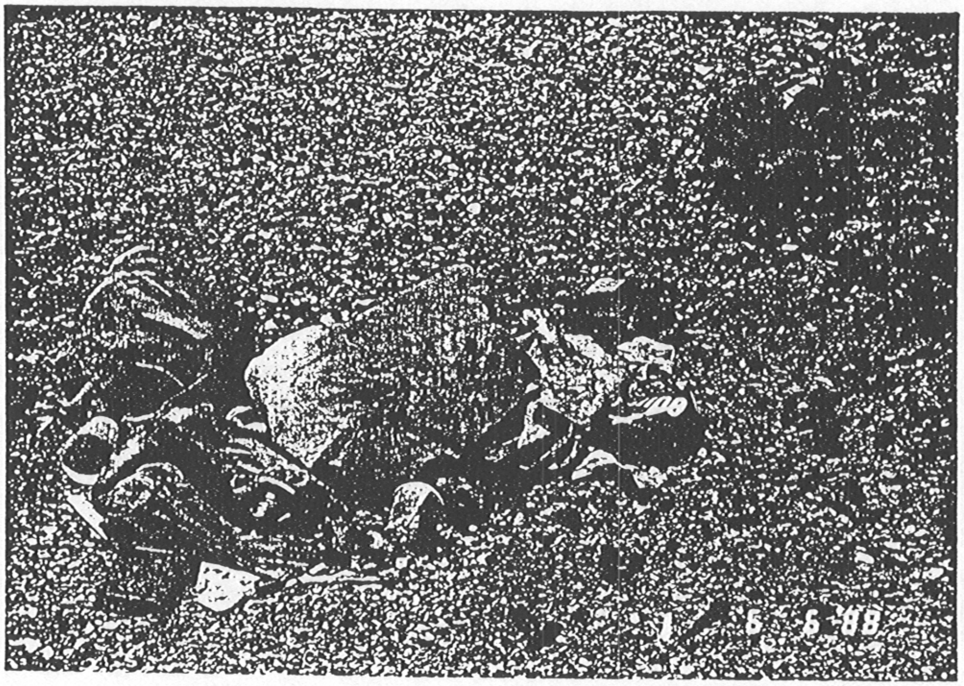

Figure 3.--Plastic bag filled by beachgoers with their garbage to prevent it from spreading on the beach.

to the lack of a nearby trash bin, the bag was left on the beach. A program of placing trash bins on some nondeclared beaches is now under way in Israel.

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NATIONAL MARINE DEBRIS DATA BASE: FINDINGS ON BEACH DEBRIS REPORTED BY CITIZENS

Kathryn J. O'Hara
Center for Marine Conservation
1725 DeSales Street, NW
Washington, D.C. 20036, U.S.A.

ABSTRACT

The Center for Marine Conservation (CMC) has established a National Marine Debris Data Base to involve citizens in the collection of standardized information on marine debris. This information collected over time will serve as a means to monitor legislative and other efforts to reduce marine debris.

During the first year of this program, more than 47,500 volunteers in 25 U.S. states and territories recorded detailed information on types and quantities of debris collected during one 3-h period in the fall of 1988. All completed data cards were returned to CMC for analysis.

The data showed that approximately 62% of the 1,973,995 debris items reported were plastic. The most common debris items were fragmented pieces of plastic and foamed plastic (Styrofoam-like). More than 56% of all debris was packaging and disposable plastic products that can be generated by a diversity of ocean- and land-based sources. Using indicator items it was found that approximately 8% of all debris reported was indicative of dumping of galley wastes by vessels, 2% was operational wastes generated during activities conducted by cargo vessels and offshore petroleum operations, 6% was fishing and boating gear, and 0.4% was sewage-associated wastes indicative of inadequate sewage treatment practices. The presence of these indicator items suggests that some of the untraceable debris items may also be generated by these sources. Only 0.09% of the debris was categorized as medical wastes suspected to be from illegal dumping, storm water runoff, or inadequate sewer systems. More than 1,000 debris items from 45 countries were reported, in addition to items traceable to 10 cruise line companies. Volunteers also reported finding more than 45 cases of wildlife entanglement or ingestion of debris, most of which were birds entangled in plastic fishing line.

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INTRODUCTION

More than 47,500 U.S. citizens participated in the first national volunteer effort to categorize the types and quantities of marine debris found in U.S. coastal areas. Information from this citizen monitoring effort was compiled by the Center for Marine Conservation (CMC)--formerly the Center for Environmental Education--in the National Marine Debris Data Base. The data base was established to gather and analyze information collected by citizens at beach cleanups conducted as part of the annual Coastweeks celebration each fall. Sponsored by the U.S. Environmental Protection Agency (EPA), National Oceanic and Atmospheric Administration, and the U.S. Coast Guard, the data base was established to utilize the efforts of citizen volunteers to identify specific debris problems in different parts of the country and to monitor the effectiveness of Annex V and other measures implemented to reduce debris. This paper presents information on how the data base was organized and national findings on the types of debris reported the first year. Detailed information on the types of debris reported and analyzed on the national, state, and local level is available from the CMC in a report entitled "Cleaning America's Beaches: 1988 National Beach Cleanup Results."

METHODS

Since 1986, the CMC has compiled extensive information on the types and quantities of marine debris found on the Texas coastline using data collected by citizens during volunteer beach cleanups. Based on these data findings, the CMC has published two reports on the debris problem in Texas which include documentation on the sources of debris and recommendations for Federal, state, and local governments, industry, and other groups to reduce the marine debris problem (Center for Environmental Education 1987, 1988).

In 1988, using the Texas data collection system as a model, the CMC initiated the first national data collection effort. After contacting all coordinators that planned to conduct beach cleanups during Coastweeks '88 (17 September-10 October), 25 states agreed to participate in a national data collection effort. For many of these states, 1988 would be their first cleanup effort and coordinators were eager to obtain information on the types and quantities of debris found on their coastlines. The timing of this national event was also important since the data collected would establish a baseline of information on beach debris prior to the enactment of MARPOL Annex V on 31 December 1988.

In order to produce a data card that would be representative of the types of beach debris found nationwide, the CMC requested comments from beach cleanup organizers as to what types of debris were prevalent on their coastline and what information was needed to evaluate the debris problem on the state and local levels. The CMC had previously developed a data card for use in Texas that reflected the great diversity of debris known to occur on the Texas coastline. (Due to circulation patterns in the Gulf of Mexico, Texas beaches receive the brunt of debris dumped into the Gulf.) Because of this diversity of debris, the Texas data card served as

BEACH CLEANUP DATA CARD

Thank you for completing this data card. Answer the questions and return to your area coordinator or to the address at the bottom of this card. This information will be used in the Center for Environmental Education's National Marine Debris Data Base and Report to help develop solutions to stopping marine debris.

Name ______________________ Affiliation ______________________

Address ______________________ Occupation ____________ Phone (____) ____________

City ______________________ State ______ Zip __________ M ____ F ____ Age: ________

Today's Date: Month ________ Day ________ Year ________ Name of Coordinator ______________

Location of beach cleaned ______________________ Nearest city ______________________

How did you hear about the cleanup? ____

SAFETY TIPS

1. **Do not go near any large drums.**
2. **Be careful with sharp objects.**
3. **Wear gloves.**
4. **Stay out of the dune areas.**
5. **Watch out for snakes.**
6. **Don't lift anything too heavy.**

WE WANT YOU TO BE SAFE

Number of people working together on this data card ______ Estimated distance of beach cleaned ______ Number of bags filled ______

SOURCES OF FOREIGN DEBRIS. Please list all items that have foreign labels.

Country	Item Found
Example: Mexico	plastic bottle - "Clarisol"

STRANDED AND/OR ENTANGLED ANIMALS (Please describe type of animal and type of entangling debris. Be as specific as you can.)

____

____

____

What was the most peculiar item you collected? ______________________________

Comments ____

____

Thank you!

PLEASE RETURN THIS CARD TO YOUR AREA COORDINATOR OR MAIL IT TO:

Center for Environmental Education
1725 DeSales Street, NW
Washington, DC 20036

A Membership Organization

Center for Environmental Education

EPA
United States Environmental Protection Agency

NOAA

200

Figure 1.--Beach cleanup data card, sides 1 and 2.

ITEMS COLLECTED

You may find it helpful to work with a buddy as you clean the beach, one of you picking up trash and the other taking notes. An easy way to keep track of the items you find is by making tick marks. The box is for total items; see sample below.

	Total
egg cartons	16
cups	22

PLASTIC	Total number of items
bags:	
trash	
salt	
other	
bottles:	
beverage, soda	
bleach, cleaner	
oil, lube	
other	
buckets	
caps, lids	
cups, spoons, forks, straws	
diapers	
disposable lighters	
fishing line	
fishing net:	
longer than 2 feet	
2 feet or shorter	
floats & lures	
hardhats	
light sticks	
milk, water gallon jugs	
pieces	
pipe thread protector	
rope:	
longer than 2 feet	
2 feet or shorter	
sheeting:	
longer than 2 feet	
2 feet or shorter	
6-pack holders	
strapping bands	
syringes	
tampon applicators	
toys	
vegetable sacks	
"write protection" rings	
other (specify)	

GLASS	
bottles:	
beverage	
food	
other (specify)	
fluorescent light tubes	
light bulbs	
pieces	
other (specify)	

STYROFOAM® (or other plastic foam)	Total number of items
buoys	
cups	
egg cartons	
fast-food containers	
meat trays	
pieces:	
larger than a baseball	
smaller than a baseball	
other (specify)	

RUBBER	
balloons	
gloves	
tires	
other (specify)	

METAL	
bottle caps	
cans:	
aerosol	
beverage	
food	
other	
crab/fish traps	
55 gallon drums	
rusty	
new	
pieces	
pull tabs	
wire	
other (specify)	

PAPER	
bags	
cardboard	
cartons	
cups	
newspaper	
pieces	
other (specify)	

WOOD (leave driftwood on the beach)	
crab/lobster traps	
crates	
pallets	
pieces	
other (specify)	

CLOTH	
clothing/pieces	

(OVER)

Figure 1.--Continued.

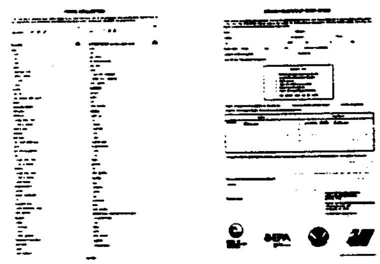
A GUIDE TO GOOD DATA COLLECTION

When you help at a beach cleanup, you'll be asked not only to remove marine debris, but to record on Data Cards the kinds and amounts of trash you find.

The information you record on these cards will be used by The Center for Environmental Education (CEE) in a national marine debris study to help policy makers on the state, federal and international levels develop solutions to ending the serious marine debris problems facing all coastal states.

Data collected since 1986 and analyzed by CEE has been used in reports, in testimony on Capitol Hill and at the International Maritime Organization meetings in London to determine how plastic trash will be handled by ships at sea and at ports all around the world.

DATA COUNTS! . . . YOUR HELP WILL MAKE A DIFFERENCE!



HELPFUL TIPS FOR DATA COLLECTORS:

1. Count items in groups of five like this ////, and record the total in the box.
2. Do not write the words "Lots" or "Many". Only numbers of items can be put into the computer.
3. Stranded Animals: In this section, please list animals you find stranded or dead on the beach and, if possible, any entangling debris items.
4. Sources: In this section, please list foreign items found and country, if identifiable.
5. Please leave natural items on the beach like driftwood, sea whip and seaweed. Avoid stepping on dune grass and plants. These things hold the sand and prevent erosion.
6. Work with a few people, have one person record the numbers while others collect and bag the trash.
7. Please return your data card to your area coordinator so that all your data will be added to state and national totals.

National Marine Debris Data Base Sponsored By:

Center for Environmental Education

EPA United States Environmental Protection Agency

NOAA

Return this card for future use

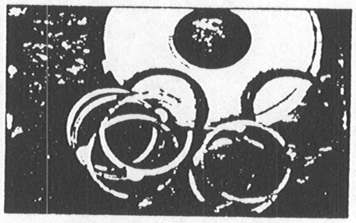
Figure 2.--Guide used by volunteers for data collection, sides 1 and 2.

GUIDE TO MARINE DEBRIS

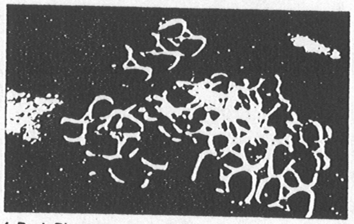
The best data recording can be done if you know what the items listed on your cards look like.

Here are some examples of unusual items you may find.

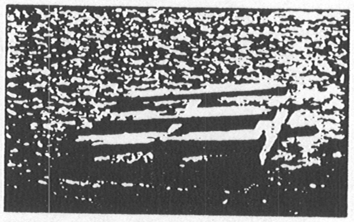
Light Sticks. Listed under plastic, these clear plastic tubes about 6 inches long are mostly used by fishermen. When new, the liquid will glow in the dark and attract fish to baited hooks.



Write Protection Rings. Listed under plastic, these are used on computer tapes on ships doing seismic testing.

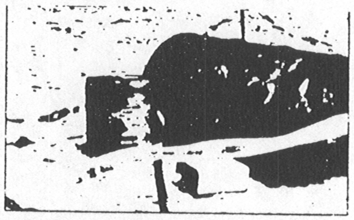


6-Pack Rings. Listed under plastic, these items are used to hold cans.

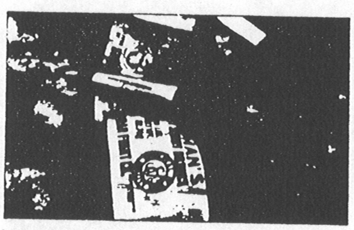


Wooden Pallets. Listed under wood, these items are used to help stack and transport cargo.

Strapping Bands. Listed under plastic, these strong, narrow, light-weight plastic bands are used to bind materials and boxes.



55 Gallon Drums. Listed under metal, these drums could contain dangerous chemicals. **Do not go near a drum** because the vapor or liquid could hurt you.



Vegetable Sacks. Listed under plastic, these large mesh bags are used to hold bulk quantities of onions, potatoes, or fruit.

Sea Whip. This yellow, orange or purple colony of animals is long, thin and has a dark string-like core. This may look like wire or rope, but it is a natural item found from North Carolina to the Gulf of Mexico. Please leave this on the beach.

FOR YOUR SAFETY

Do not approach any 55 gallon drums. They may contain dangerous liquids. Even the vapor could harm you. Leave the drum, but record it on your card.

Do not go into the dunes: snakes may be there.

Be very careful of broken glass and other sharp objects.

Wear gloves.

Don't lift anything heavy.

THANK YOU for your help and interest in keeping the coast and ocean safe for all of us and for marine wildlife!

Figure 2.--Continued.

an important model for the subsequent development of a system for categorizing and classifying beach debris on a national level.

The resulting data card was divided into eight major category types--plastic, glass, Styrofoam, metal, rubber, paper, wood, and cloth (Fig. 1). ("Styrofoam" was used instead of the more technical term "foamed plastic" because it was felt that volunteers would more readily recognize this term.) In total, the data card listed 64 types of debris items. In addition, for each major category there was a listing for "other" to ensure that items not listed on the data card were recorded. Data cards also requested specific information on the sources of foreign debris items as indicated by product labels or other markings, observations of entangled or stranded marine wildlife, observations of peculiar debris items, and comments from volunteers.

With funding from the EPA, the CMC distributed 43,000 data cards to cleanup organizers in the 25 participating states and territories. One thousand additional data cards in the Spanish language were sent to Puerto Rico.

The CMC also developed and distributed 43,000 copies of a 1-page guide for data collection (Fig. 2). The guide gave information on how to use the data card, identified certain debris items that might not be familiar to volunteers, and explained how this information would be used to compile a national assessment of beach debris. Volunteers were encouraged to work in pairs during the cleanup--one person to pick up trash while the other recorded debris.

Each state beach cleanup coordinator was responsible for distributing the data cards and guides to their volunteers and for returning all completed data cards to the CMC for data entry and analysis. All data were then entered into the CMC's National Marine Debris Data Base and analyzed on the basis of national, state, and local findings.

FINDINGS

More than 47,500 volunteers participated in beach cleanups in 1988 in 25 U.S. states and territories (Table 1). One 3-h cleanup was conducted in every coastal state. While the data collected from these cleanups provided a means to assess the debris problem in marine areas, it also provided interesting insights into the extent of the debris problem in inland waters of the United States.

Beach cleanup volunteers covered more than 5,600 km (3,500 mi) of U.S. shorelines and collected nearly 1,000 tons of debris. The methods used to weigh debris varied from state to state, and therefore the weight of debris collected is not exact. However, it is of interest to note that the greatest amount of trash per mile of beach was reported in the states bordering the Gulf of Mexico, particularly Louisiana, Mississippi, and Texas.

On analyzing the data cards, it became obvious that the number of debris items recorded was only an estimate of the true amounts. Some

Table 1.--Number of volunteers, distance cleaned, and amount of debris collected during 1988 beach cleanups (asterisk indicates information not available).

State	Number of volunteers	Distance cleaned (miles)	Distance cleaned (kilometers)	Debris collected (pounds)	Debris collected (kilograms)	Debris per mile (pounds)	Debris per mile (kilograms)
Alabama	630	40	64	8,340	3,786	208.50	94.66
Alaska	238	10+	16+	10,300+	4,676+	*	*
California	5,700	1,100	1,770	200,000	90,800	181.82	82.55
Connecticut	14	2	3	190	86	95.00	43.13
Delaware	650	54	87	6,054	2,749	112.11	50.90
Florida	10,676	914.6	1,471.6	388,000	176,152	424.23	192.60
Georgia	268	50	80	200,000	90,800	4,000.00	1,816.00
Hawaii	3,037	102.8	165.4	100,000	45,400	972.76	441.63
Louisiana	2,700	77	124	180,000	81,720	2,337.66	1,016.30
Maine	1,410	114	183	15,200	6,901	133.33	60.53
Maryland	171	18	29	3,750	1,702	208.33	94.58
Massachusetts	2,200	150	241	50,000	22,700	333.33	151.33
Mississippi	1,200	30	48	90,000	40,860	3,000.00	1,362.00
New Jersey	250	15.4	24.8	10,021	4,550	652.41	296.19
New York	150	4.2	6.7	4,560	2,070	1,085.71	492.91
North Carolina	3,500	150	241	94,000	42,676	626.67	284.51
Oregon	2,200	120	193	28,400	12,894	236.67	107.51
Pennsylvania	174	7	11	2,445	1,110	349.28	158.57
Puerto Rico	407	17.3	27.8	12,640	5,739	730.64	331.71
Rhode Island	500	100	161	15,000	6,810	150.00	68.10
South Carolina	3,000	198	319	30,000	13,620	151.52	68.79
Texas	5,987	120.6	194.0	428,000	194,312	3,548.92	1,611.21
Virginia	130	19.8	31.9	12,900	5,857	651.51	295.79
Virgin Islands	435	3.2	5.1	*	*	*	*
Washington	1,904	100+	161	64,000	29,056	540.00+	245.16+
Total	47,531	3,517.84	5,660.2	1,953,800	887,025		

volunteers did not count debris items but only commented on the tremendous amounts of debris found. In cases where actual counts were not made, the cards were not added to the data base. But for the most part, volunteers made deliberate and careful efforts to record information. Some who could not identify certain debris items actually sent this trash to the CMC for identification.

Understandably, data collected during volunteer beach cleanups are highly variable and therefore cannot be interpreted exactly, but beach cleanup data can reveal important trends in the relative types, quantities, and distribution of debris. For instance, the data showed that most of the debris found on our nation's coastline is plastic (including Styrofoam). The amount of plastic debris reported surpassed all other categories, accounting for 1,222,708 of the 1,973,995 debris items reported, or approximately 62% (Fig. 3). The remaining debris items consisted of approximately 11.8% paper, 11.4% metal, 9.5% glass, 2.3% wood, 1.8% rubber, and 1.3% cloth. This abundance of plastic debris is also apparent on the state level (Table 2).

The most common debris items reported nationwide were fragmented pieces of plastic and foamed plastic (Styrofoam-like). The data indicate that these plastic pieces accounted for more than 13% of all debris reported. The 12 most common debris items recorded were plastic eating utensils, metal beverage cans, foamed plastic cups, glass beverage bottles, plastic caps and lids, paper pieces (or fragments), plastic trash bags, miscellaneous types of plastic bags (other than trash or salt bags), glass pieces (or fragments), and plastic soda bottles. Collectively, these 12 debris items constituted more than 56% of all debris items recorded (Table 3). Other debris items reported in abundance included approximately 42,700 metal bottle caps, 30,800 plastic six-pack connector rings for

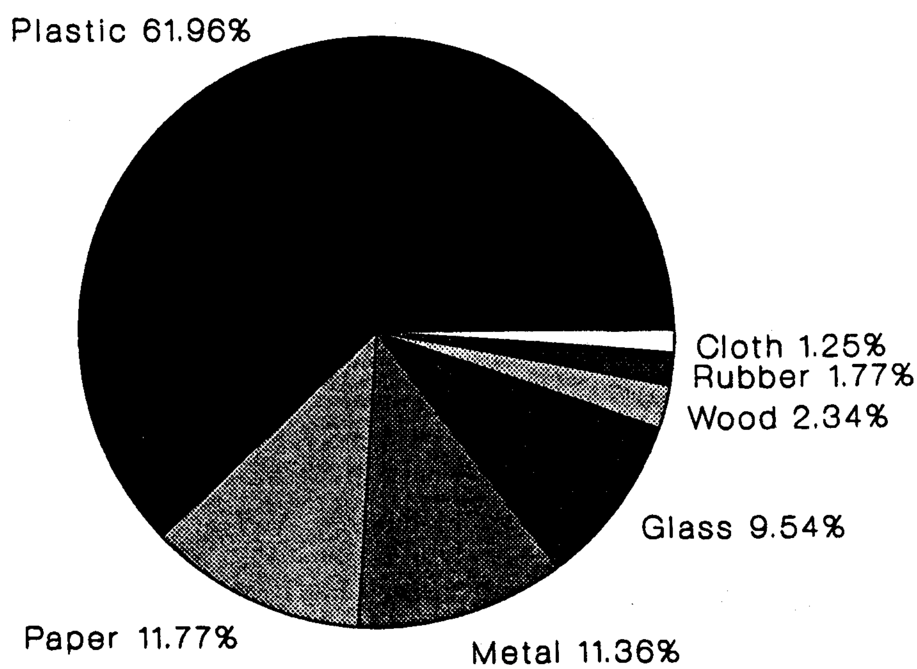


Figure 3.--National composition of debris reported.

Table 2.--Composition of total debris reported during 1988 beach cleanups.

	Percent of total debris collected						
	Plastic	Metal	Paper	Glass	Wood	Rubber	Cloth
National	61.94	11.36	11.77	9.54	2.34	1.80	1.25
By state							
Alabama	63.48	10.81	10.58	10.21	1.87	1.90	1.15
Alaska	56.45	17.83	6.04	15.79	1.21	1.77	0.91
California	47.97	12.11	19.43	15.86	1.42	2.04	1.19
Connecticut	65.99	7.85	7.70	10.54	3.51	2.69	1.72
Delaware	56.82	15.16	14.02	6.78	2.60	2.88	1.76
Florida	59.67	13.31	11.35	10.27	2.72	1.34	1.33
Georgia	57.42	21.13	7.12	9.26	1.99	1.98	1.10
Hawaii	52.14	11.86	16.70	14.54	1.36	2.22	1.19
Louisiana	74.42	7.37	3.58	9.32	1.71	1.87	1.74
Maine	59.69	10.85	12.38	9.74	2.30	3.60	1.45
Maryland	55.79	21.54	7.38	9.10	2.15	2.59	1.46
Massachusetts	61.03	11.40	14.17	7.06	2.49	2.29	1.56
Mississippi	66.29	12.49	7.45	9.63	2.21	1.08	0.85
New Jersey	94.53	1.66	2.47	0.13	0.13	0.85	0.22
New York	77.63	8.99	6.59	4.15	1.02	0.74	0.88
North Carolina	51.81	13.62	20.23	7.22	4.10	1.63	1.39
Oregon	70.16	5.62	14.98	4.85	1.72	1.60	1.10
Pennsylvania	55.85	10.33	22.92	5.19	1.20	2.35	2.17
Puerto Rico	43.36	19.08	11.54	22.09	2.29	0.58	1.05
Rhode Island	60.63	13.20	13.34	6.96	1.26	3.34	1.26
South Carolina	58.86	11.82	16.71	5.81	4.00	1.69	1.11
Texas	76.54	6.73	3.87	8.58	1.63	1.60	1.05
Virginia	61.42	10.65	8.80	8.87	4.29	4.74	1.22
Virgin Islands	60.36	15.23	6.39	13.12	2.44	1.14	1.33
Washington	57.46	7.12	24.58	8.12	1.24	1.07	0.41

beverage cans, 27,600 small pieces of plastic sheeting, 25,200 paper cups, 22,500 foamed plastic fast-food containers.

This information indicates that the majority of debris items found on U.S. shorelines are packaging and disposable plastic products that can be generated by a diversity of ocean- and land-based sources. Certain items, however, are traceable to specific debris sources, and can be used as "indicators" of dumping by maritime and other groups. These indicator items were first identified by the CMC in 1986 with the assistance of the Texas Coastal Cleanup Steering Committee, which included representatives of marine industry groups familiar with the types of debris that could be generated by industry members.

Table 3.--Twelve most common debris items reported during 1988 beach cleanups.

Debris item	Total number reported	Percent of total debris collected
Plastic pieces (or fragments)	134,685	6.82
Small foamed plastic (Styrofoam) pieces	125,725	6.37
Plastic cups, spoons, forks, and straws	112,465	5.70
Metal beverage cans	99,847	5.06
Foamed plastic (Styrofoam) cups	95,807	4.85
Glass beverage bottles	95,028	4.81
Plastic caps and lids	90,998	4.61
Paper pieces	85,864	4.35
Plastic trash bags	78,025	3.95
Miscellaneous types of plastic bags	74,672	3.78
Glass pieces	65,819	3.33
Plastic soda bottles	58,116	2.94
Total	1,117,051	56.59

Using this information, 28 indicator items were identified which fall under four categories: 1) galley wastes generated by crew members on vessels, 2) operational wastes generated during activities conducted by cargo vessels and offshore petroleum operations, 3) fishing and boating gear, and 4) sewage-associated wastes indicative of inadequate sewage treatment practices. Table 4 lists the debris items included under each of these categories. A fifth category, medical wastes, was also identified using plastic syringes as the indicator item. Although the source of syringes as beach debris has not been clearly identified, syringes are suspected to be from illegal dumping, storm water runoff, or inadequate sewer systems.

These 28 indicator items accounted for more than 16% of the debris reported nationwide, with approximately 8% galley wastes, 6% attributable to recreational and commercial fishing and boating, and 2% operational-type wastes. Sewage-associated wastes and medical wastes were comparatively less common, accounting for 0.4 and 0.09% respectively. This information should not be interpreted to mean that these are the only wastes generated by specific ocean- and land-based sources. Rather, the presence of indicator items may show that some of the untraceable debris items are also be generated by these same sources.

Furthermore, comparisons of indicator items on the state level showed regional differences in the amount of debris traceable to these sources. For instance, the amounts of galley and operational-type wastes found in states bordering the Gulf of Mexico were much higher than the national figures. On the other hand, while offshore-generated wastes were notably absent on inland beaches on Lake Erie, Pennsylvania, the amount of sewage-associated wastes reported from the Pennsylvania cleanup was six times

Table 4.--Categories and quantities of indicator items used for national assessment of debris reported during 1988 beach cleanups.

Category	Indicator items	Total number reported	
Galley wastes	Plastic trash bags	78,025	
	Plastic milk and water gallon jug	26,148	
	Plastic bleach, cleaner bottles	19,300	
	Foamed plastic meat trays	14,721	
	Foamed plastic egg cartons	9,526	
	Plastic vegetable sacks	6,770	
Subtotal		154,490	(7.83%)
Fishing or boating gear	Plastic rope	47,786	
	Plastic fishing line	16,563	
	Plastic oil and lubricant bottles	12,002	
	Plastic light sticks	9,307	
	Plastic fishing nets	8,136	
	Foamed plastic buoys	7,876	
	Plastic floats and lures	5,980	
	Rubber gloves	5,748	
	Plastic salt bags	3,797	
	Wooden fish and crab traps	1,309	
	Metal fish and crab traps	1,281	
Subtotal		119,785	(6.07%)
Operational wastes	Plastic strapping bands	11,665	
	Plastic sheeting longer than 60 cm (2 ft)	7,383	
	Glass light bulbs	6,905	
	Plastic pipe thread protectors	5,084	
	Write-enable protection rings	3,054	
	Fluorescent light tubes	2,209	
	Wooden pallets	1,737	
	Wooden crates	1,075	
	Plastic hardhats	857	
Subtotal		39,969	(2.03%)
Sewage-associated wastes	Plastic tampon applicators	7,584	(0.38%)
Medical wastes	Plastic syringes	1,718	(0.09%)
Total number of indicator items		343,546	(16.39%)

greater than the national figure, indicating that inadequate sewer systems were a problem in this area.

By noting product labels and other markings, volunteers also reported more than 1,000 foreign label items from 45 countries. In addition, debris from 10 cruise line companies was reported.

Finally, during the 3-h beach cleanup, volunteers reported finding more than 45 cases of wildlife entanglement or ingestion of debris. Of these, more than 40 were birds, most of which were entangled in plastic fishing line.

DISCUSSION

Due to the diversity of debris items and their multiple uses, data collected during beach cleanups cannot realistically be used to estimate total amounts of debris found in marine areas or the exact sources of debris items. However, comparison of relative amounts of debris can reveal important national, state, and local trends in the types and distributions of beach debris. In particular, the first year of the National Marine Debris Data Base demonstrated that plastics account for the majority of waste on our nation's shorelines. Having established a baseline of information on the types and quantities of plastic waste, future beach cleanups can help to monitor legislative and other efforts to control the discharge of plastic trash into marine areas.

By monitoring the presence of indicator items, citizen beach cleanups can also serve to identify what groups are not complying with offshore dumping regulations. This type of information is especially important for developing solutions to the debris problem on the state and local levels.

The great majority of items reported during beach cleanups, however, are virtually untraceable to their specific sources. Yet this information contributes greatly to the underlying theme of a beach cleanup--increased awareness. Since much of this debris consists of items that are used by the general public, those who participate in beach cleanups learn that marine industries are not the only sources of marine debris and that the solution lies with us all. Others who do not participate in beach cleanups hear about data results in the press and media and may consider proper disposal of their trash. Finally, it is hoped that those who manufacture or distribute products that are reported as debris will realize the need to initiate and support efforts that encourage proper disposal and prevent these items from becoming debris.

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GUIDELINES FOR THE DESIGN OF BEACH DEBRIS SURVEYS

Christine A. Ribic*
Center for Quantitative Science in Forestry, Fisheries, and Wildlife
University of Washington
Seattle, Washington 98195, U.S.A.

and

Scott W. Johnson
Alaska Fisheries Science Center Auke Bay Laboratory
National Marine Fisheries Service, NOAA
Auke Bay, Alaska 99821, U.S.A.

*Present address: U.S. EPA Environmental Research Laboratory, 200 SW 35th Street, Corvallis, OR 97333, U.S.A.

ABSTRACT

Beach surveys give valuable information as to the types, quantities, and sources of marine debris floating at sea. With the passage of Annex V of MARPOL, however, a decrease in marine debris needs to be detected to demonstrate the effectiveness of mitigating legislation. In order to detect a decrease in marine debris washed ashore, beach survey methodology will need to be standardized. Standardization of survey methods based upon the authors' experience in Alaska is discussed, as is the design of beach surveys to detect between 30 and 50% decreases in the amount of marine debris washed ashore after 5 years, with 95% confidence and power of 80%. Preliminary findings suggest that the number of surveys of a given beach needed to detect a 50% change will be large (bimonthly surveys for 5 years). Annual surveys have low power for detecting a 50% decrease after 5 years, although this result depends on estimates of within-beach variability. Hopefully, this proposal will lead to a discussion of standardized methodology for marine debris beach surveys and the detection of change.

INTRODUCTION

Plastics and other synthetic materials discarded at sea constitute "marine debris" and are now recognized internationally as a form of marine pollution. There is no consensus, however, on how to monitor marine debris after it has washed ashore. Standardized protocols for monitoring other

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pollutants have been established; examples are tar ball pollution (IOCARIBE 1980) and chemical pollution (Kullenberg 1986). Developing standardized methods will make planning easier and comparison between areas more meaningful.

One of the easiest and most cost-effective methods for arriving at an index of marine debris pollution is the beach survey (Dixon and Dixon 1981; Merrell 1985). The use of beach surveys as indices of floating marine debris, however, requires planned surveys with a clear statement of objectives and assumptions.

This paper has two objectives: (1) to outline the steps involved in planning a beach survey, and (2) to consider two different sampling designs for detecting a decrease in marine debris following the implementation of MARPOL Annex V.

METHODS

A literature review was conducted to identify all published papers on the subject of beach surveys of marine debris excluding tar. Tar pollution was excluded because of the widespread use of standardized techniques to census tar balls on beaches (IOCARIBE 1980). Studies were divided into two groups. The first group focused on describing marine debris on the study area. The second focused on using the beach survey as an indicator of floating marine debris. Next, for all studies, we checked whether the entire beach was surveyed or only portions (transects) of it. Studies were then put into a conceptual framework proposed for planning beach surveys.

The design of surveys to investigate the effect of mitigating legislation (MARPOL Annex V) to reduce the input of debris into the ocean was based on intervention analysis of time series (Hipel et al. 1978; Lettenmaier et al. 1978; Barnard et al. 1985). We also considered a repeated measures 1-factor experimental design (Myers 1972) as a second design.

First, we were interested in determining the sample size (number of surveys) needed over 5 years to detect a 30 to 50% change in the amount of marine debris with power (probability of detecting the change) of 0.80 and an alpha of 0.05. An estimate of the variance between years was based on data in Merrell (1985) for Amchitka Island 1972-74. This estimate was used to translate the percentage change into trend or standard deviation ratios needed to use the graphs in Lettenmaier et al. (1978). We also considered the effect on power of changing sample sizes in detecting a standardized difference of 1 standard deviation (45% change) over 5 years for alpha = 0.05 and alpha = 0.20. In all cases, gamma, the ratio of number of samples before mitigation to total number of samples, was 0.15 or 0.20. Lettenmaier et al. (1978) showed that gamma should be small for the linear intervention model we used.

Secondly, we were interested in the power associated with doing annual surveys for 5 years and detecting a change between 20 and 50% and an alpha of 0.10. Power was taken from Cohen (1977). For Amchitka Island, an estimate of within-beach variability was calculated from Merrell (1980) for 1972-74 and a mean of 361 pieces of debris per kilometer (Merrell 1984) was used to translate percent change into pieces of debris per kilometer. For the Yakutat area, an estimate of within-beach variability was calculated from data collected 1984-87, and a mean of 205.95 pieces of debris per kilometer was used to translate percent change into pieces of debris per kilometer.

RESULTS

General Beach Survey Design Considerations

The process of beach survey design is summarized in Figure 1. From the published literature, most beach surveys have been short term (one-time surveys) and focused on a single study area (individual beaches) (Cundell 1973; Gregory 1977, 1978, 1983; Bigg 1982; Gregory et al. 1984; Neilson 1985; Willoughby 1986; Henderson et al. 1987; Center for Environmental Education 1988; Marine Plastic Debris Task Force 1988). This focus on the shoreline or beach has led to massive volunteer efforts to clean beaches with little or no reporting of data. These types of studies are valuable for cleaning beaches and gathering information on the types and composition of debris on various coastlines. But quantitative analysis of such data is restricted due to small sample sizes (an annual cleanup means that the sample size is 1) and missing data (especially where data are voluntarily reported).

Few studies stated that their objective was to use the beach debris surveys as an index of floating marine debris. Most studies using beach surveys as an index of oceanic debris were European (Dixon and Cooke 1977; Dixon and Dixon 1981; Shell UK 1985; Federal Republic of Germany 1986; Vauk and Schrey 1987). In the United States, the only published program using beach debris surveys as an index of marine debris is that of Merrell and Johnson in Alaska (Merrell 1980, 1984, 1985; Merrell and Johnson 1987; Johnson 1988; Johnson and Merrell 1988).

In all cases, a precise definition of the sampling unit is needed (Fig. 1). The natural unit is the entire beach from the water's edge to the seaward limit of terrestrial vegetation. In Alaska, most beaches surveyed are 1 km long (Merrell 1985). In England, Dixon and Dixon (1981) used transects, noting that there was too much debris to be totally counted. Where possible, we propose that the entire beach be the survey unit, with results standardized to length (e.g., debris per kilometer). In all cases, the same sampling units should be surveyed over time to minimize variability between surveys.

Before the actual sampling units are chosen, it is best to survey the area of interest to determine beach characteristics and debris distribution (Fig. 1). This is where massive volunteer cleanup efforts can be utilized to help plan the study. It is important to know substrate type, beach slope, prevailing winds, ease of access, and recreational use of the area (Dixon and Dixon 1981; Merrell 1985). Depending upon one's objective, all these factors can influence the choice of beach. Preferred beaches are

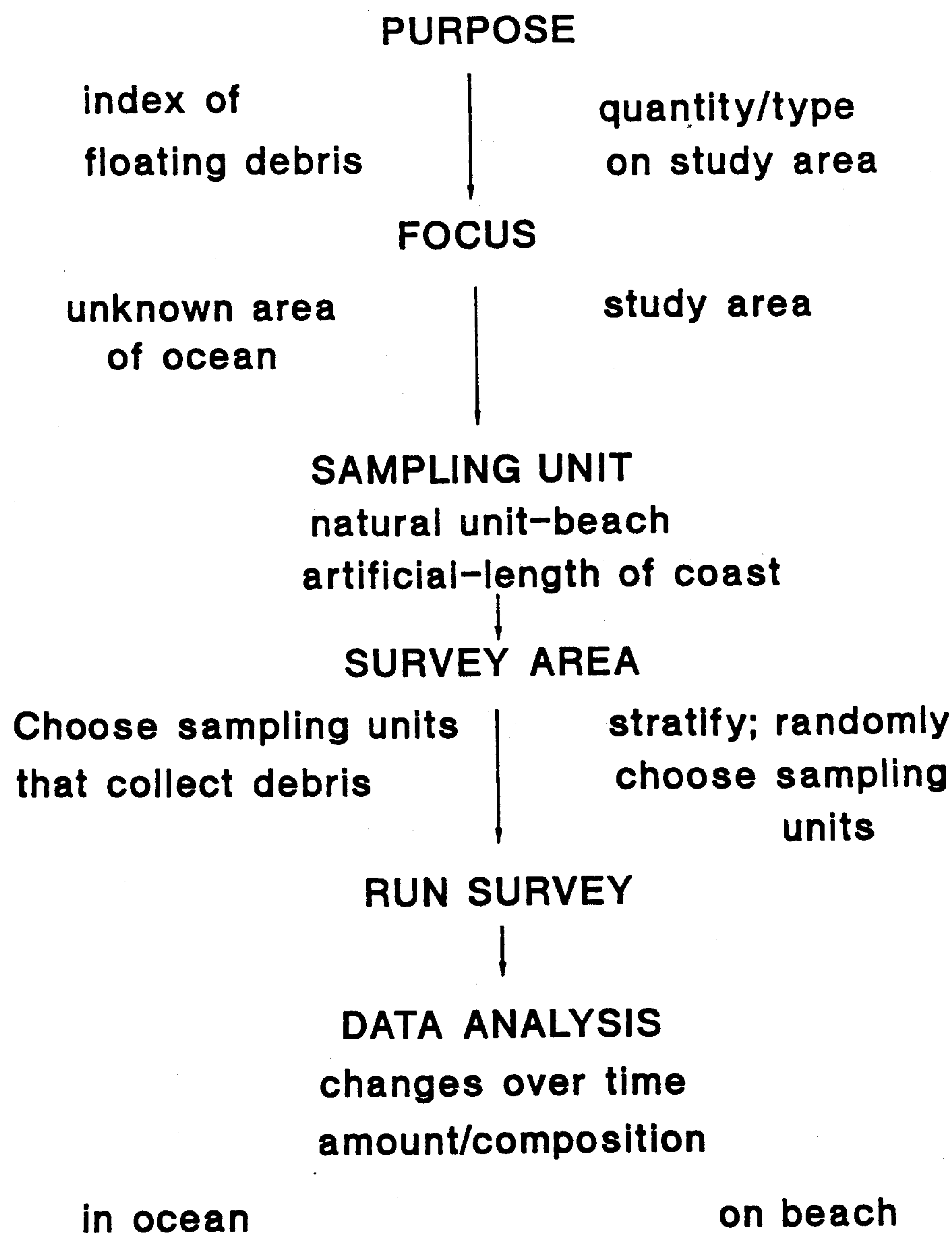

Figure 1.--Steps in the design of beach surveys.

moderate-to-steep sand or gravel beaches that are exposed to open ocean. Beaches should have 1 km of similar substrate and scope and be as far as possible from urban areas to minimize bias from local refuse.

Analysis of beach survey data depends on the purpose of the study as well as on the method of data collection. For example, Henderson et al. (1987) examined the distribution of net fragments on the beaches of the Northwestern Hawaiian Islands because they were interested in the location of the debris within the beach. Comparisons between years for beaches is possible with the following caveat. The common statistical tests such as t-tests and analysis of variance (Zar 1986) are not appropriate here because the same beaches are censused over time. The more appropriate techniques are paired-t tests, repeated measures analyses of variance, and their nonparametric equivalents (Conover 1980; Zar 1986). The use of time-series analysis is not appropriate because of the extremely low sample sizes usually found in these studies.

If the focus of the study is an index of floating marine debris, changes over time are of interest but the change is for an unknown area of ocean (Fig. 1). It is not appropriate to extrapolate to other beaches. Merrell (1980) stated that he had problems in extrapolating debris abundance to other beaches.

Beach Surveys as Indicators of Oceanic Debris

There are at least two important assumptions made when using beach surveys as indicators of floating marine debris (Ribic and Bledsoe 1986). The first assumption is that the debris at time t (the first sampling period) is not the same debris as that at time t+1 (the second sampling period). In other words, the same debris is not counted twice. The easiest way to fulfill this assumption is by clearing the beach of all surface debris after each survey (e.g., Cundell 1973; Shell UK 1985; Federal Republic of Germany 1986; Henderson et al. 1987). Sometimes this is not practical, especially when debris (e.g., trawl web) is partially buried or snarled on drift logs. In this case, debris can be tagged (Johnson 1988) for identification on later surveys. Tagging studies can provide information on minimum time between surveys as well as information on the loss and deposition rates of beach debris.

The second assumption is that the amount of debris on a beach is related to the amount of debris floating in an unknown area of ocean, and that this area is the same between surveys. In other words, the oceanic area swept onto the beach, when integrated over time, is the same between surveys. This is an important assumption if we want to conclude that a decrease in beach debris over time is due to mitigation measures and not due to a change between years in the area swept onto a beach. We would encourage a study of this assumption if beach surveys are to be useful as indicators of marine debris.

Detecting Change Due to Implementation of Legislation

We will model the potential impact of mitigating legislation (MARPOL Annex V) on the quantity of marine debris washed ashore with the simplest model: A gradual linear decrease in marine debris over time after the enactment of the law.

An extremely high survey effort over years will be needed to detect any decrease between 30 and 50% (Table 1). For a 45% decrease, a sample size of 180 translates into a beach survey 3 out of 4 weeks per month per year for 5 years. Detecting a 50% change would call for almost biweekly surveys every month for 5 years. However, the probability of detecting a 45% change is nil using annual surveys and is low using quarterly surveys (Table 2), i.e., the change would have to be so drastic that no statistics would be needed to notice it.

Using a different approach, we looked at treating annual debris counts as a repeated measure on beaches. An estimate of within-beach variability for Amchitka Island was 203 pieces of debris per kilometer. For the Yakutat area, an estimate of within-beach variability was 57 pieces of debris per kilometer. We then calculated minimum and maximum power for changes between 20 and 50% (Table 3) at alpha = 0.10. For Amchitka Island, the probability of detecting any change was low due to the high variability within beaches. Detecting a change of 50% with annual surveys has a power as low as 0.43-0.76 (Table 3). For the Yakutat area, however, the probability of detecting a change of 40% or more using annual surveys was between 0.50 and 0.95 (Table 3). This is due to the low within-beach variability.

DISCUSSION

We are just beginning to realize the magnitude of the marine debris problem. In order to quantitatively assess the problem, standardized beach surveys can be used. Standardization of methodology will make comparisons between areas easier and will ensure the validity of estimates.

It is important for researchers to state explicitly the objectives of their beach debris surveys. Whether or not a survey will be used as an index of floating marine debris affects the survey design from the choice of a particular sampling unit to the data collection and analysis.

A key assumption in using beach surveys to detect a difference due to mitigation is that the area of ocean swept onto the beach is constant between years. Firm conclusions about the effect of mitigating measures in decreasing floating marine debris based on beach debris surveys depend on this assumption. An attempt, therefore, should be made to evaluate its reasonableness.

Beach debris surveys are useful for determining the types and quantities of debris as well as entanglement potential. But the use of beach surveys to detect change with any degree of confidence and power will be more difficult. Preliminary sample size estimates are large for detecting a 50% decrease (power of 0.80; alpha = 0.05). Whether or not annual surveys will be adequate for detecting a 50% change (alpha = 0.10) depends on the estimate of within-beach variability. On Amchitka Island, variability on the same beach is large, and annual surveys will not be adequate for detecting a 50% decrease. In the Yakutat area, however,

Table 1.--Required sample sizes for detecting changes between 30 and 50% of beach debris for alpha = 0.05, power = 0.80, gamma = 0.20, and an estimate of variability = 103.429 pieces of debris per kilometer for a linear intervention model. n = total surveys spread over 5 years.

Percent change	Standardized difference	n
30	0.71	1,000
40	0.95	200
45	1.1	180
50	1.2	100

Table 2.--Probability of detecting a 45% change over 5 years (power) with a gamma = 0.15.

	Power	
	alpha	
n	0.05	0.20
5 (annual)	<0.10	<0.10
20 (quarterly)	0.20	0.45

Table 3.--Minimum and maximum power for a one-factor repeated measures design with alpha = 0.10 and k = 5 for detecting changes in beach debris between 20 and 50% for Amchitka Island and Yakutat beaches.

Percent change	Amchitka Island		Yakutat	
	Minimum	Maximum	Minimum	Maximum
20	0.14	0.22	0.20	0.34
30	0.22	0.38	0.33	0.63
40	0.30	0.58	0.52	0.87
45	0.46	0.67	0.61	0.94
50	0.43	0.76	0.71	>0.94

within-beach variability is lower, and annual surveys have a chance of detecting a 50% decrease over 5 years.

Designing a study to measure the impact of legislation to decrease the amount of marine debris will take more planning and a greater commitment of resources. As can be seen from our preliminary findings, sample sizes to detect a given change with stated precision will be large. An improved design could be constructed if we had better variance estimates of debris between beaches as well as within beaches, as well as consensus about the magnitude of the change we would like to detect. In addition, identifying and understanding factors that affect the deposition of debris will be critical in evaluating the success of mitigating legislation.

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THE COMPOSITION AND ORIGIN OF MARINE DEBRIS STRANDED ON THE SHORES OF SUBANTARCTIC MACQUARIE ISLAND

David J. Slip and Harry R. Burton
Australian Antarctic Division
Kingston, Tasmania, 7050, Australia

ABSTRACT

The coastline of subantarctic Macquarie Island (lat. 54°35'S, long. 158°55'E) was surveyed over an 8-week period in 1988 to determine types, quantities, and possible sources of marine debris. Lost fishing gear consisted of buoys, ropes, and net fragments. Gear from both trawling and longline fishing operations were represented, with debris identified from Russian, Polish, Japanese, Taiwanese, and South American sources. Three types of litter which potentially entangle marine mammals were found: plastic packing straps, ropes, and net fragments. Plastic bottles, small plastic fragments from broken plastic bottles, and small pieces of expanded polystyrene were common. Litter accumulated in highest densities on open beaches of the west coast of the island. Overall density of marine debris was less than densities reported for islands in the South Atlantic Ocean and the Indian Ocean, or from the coast of Alaska.

INTRODUCTION

Plastic litter and other man-made debris have been recognized as major pollutants of open ocean and coastal surface waters (Shomura and Yoshida 1985; Day and Shaw 1987; Pruter 1987). The distribution of this debris is widespread. Debris has been reported from coastlines near populated, industrial regions of the world (Shiber 1979, 1982), and from open water such as the Mediterranean Sea and the North Sea, which are traversed by busy shipping lanes (Morris 1980; Dixon and Dixon 1983; McCoy 1988), as well as from remote areas such as Alaska (Merrell 1984; Merrell and Johnson 1987) and islands in the Southern Ocean (Gregory 1987; Ryan 1987b; Ryan and Watkins 1988). The slow breakdown of many artifacts allows them to disperse over long distances, often distant from their source (Carpenter and Smith 1972; Ryan 1987b).

Little is known of the impact and fate of much of this debris, although adverse effects through entanglement and ingestion have been documented in seabirds (Azzarello and van Vleet 1987) and marine mammals (Bonner and McCann 1982; Fowler 1985; Laist 1987). The long lifespan and

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widespread dispersal of such litter make it important to monitor strandings of artifacts in remote sectors of the Southern Ocean in order to identify the major sources of debris and to determine a baseline index of distribution and relative abundance. Parties to the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) have agreed to monitor and report the occurrence of artifacts in the Southern Ocean (Morris 1985). Difficulties in monitoring floating debris, particularly small plastic artifacts, highlight the importance of beach surveys in determining densities, abundance, and sources of such debris.

The present study identifies the types and origins of marine litter stranded at Macquarie Island.

STUDY AREA AND METHODS

Macquarie Island (lat. 54°35'S, long. 158°55'E) is situated in the Southern Ocean. It lies on the Macquarie Ridge approximately 1,500 km south-southeast of Tasmania and 640 km southwest of the Auckland Islands. The island is approximately 34 km long and varies in width from 250 m at the northern isthmus to a maximum of 5 km midway along the island. Commercial sealing took place on the island from 1810 until 1919 (Cumpston 1968). Since 1948, the Australian National Antarctic Research Expeditions (ANARE) have maintained a permanent station on the island. Most of the present day land-based activity on the island is centered around the isthmus and at the six field huts on the island. The nearest ship-based fishing activities occur over the Campbell Plateau, about 700 km to the northeast, and around the Kerguelen group, 5,000 km to the west.

The entire coastline of Macquarie Island (ca. 94 km) was surveyed for stranded artifacts over a 6-week period from June to August 1988. All sizable artifacts (excluding wooden objects) were identified (where possible) from manufacturers' marks in order to determine their origins. All objects were collected and removed from the beaches. Larger objects, such as fishing buoys and floats, were recorded, marked, and stockpiled above high water level at various locations around the island. The rocky nature of much of the coastline precluded sampling of items smaller than 10 mm. Artifacts were categorized according to type of material: plastic, metal, glass, and other. Objects collected from the beach below the ANARE station refuse dump were not included in the survey. Similarly, wooden objects were not included, to avoid confounding the results with wooden remains from sealing activities and old shipwrecks.

The coastline was surveyed in seven convenient arbitrary sectors (Fig. 1), which varied in size and topography. Some sectors were dominated by rock shelf coastline with large boulders, while others had more open beach (Table 1). This is the first survey of marine debris undertaken at Macquarie Island.

RESULTS

A total of 1,034 man-made artifacts was recorded from 94 km of shoreline at Macquarie Island. This represents a density of 11

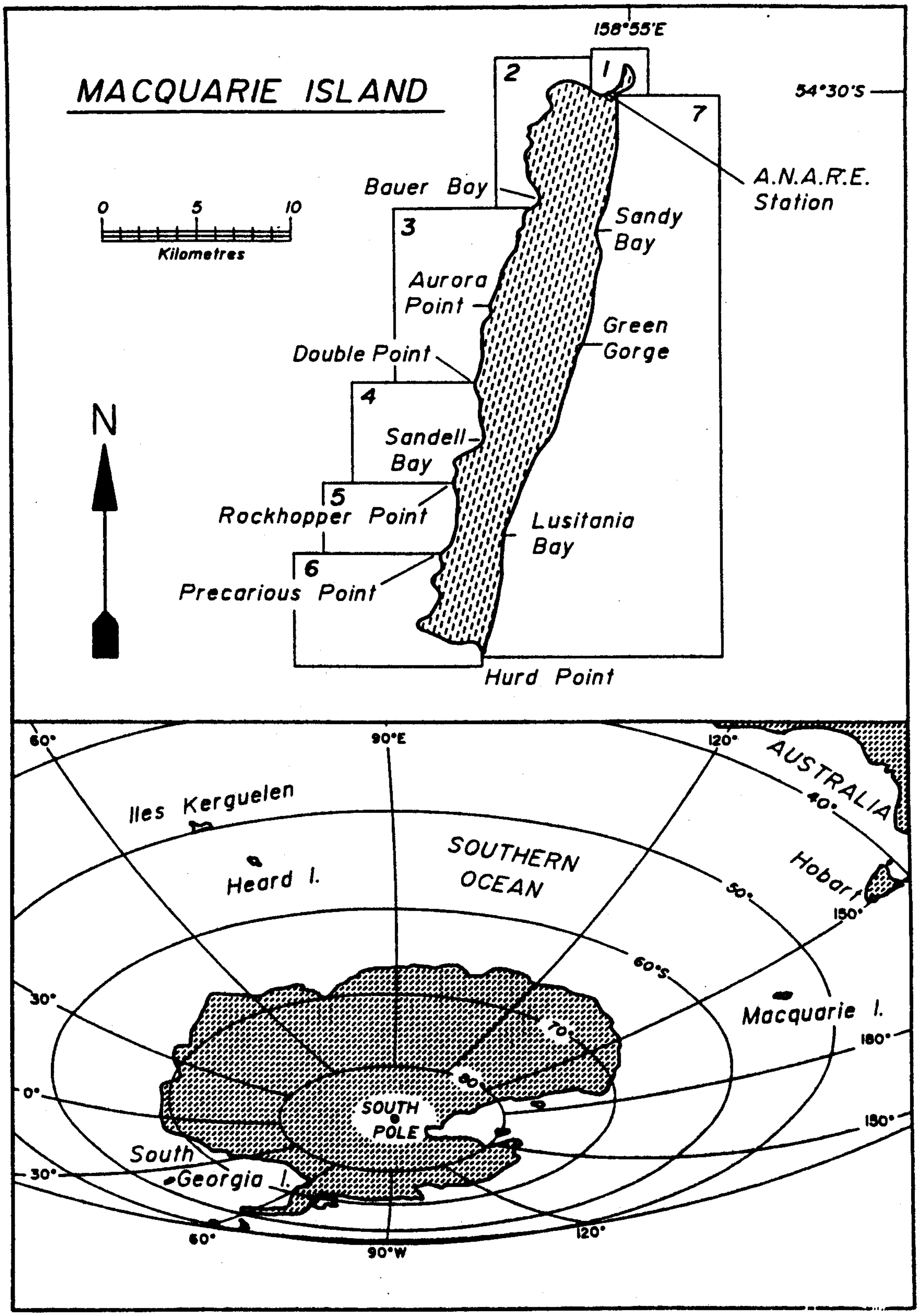

Figure 1.--Macquarie Island, showing its position in the Southern Ocean and the location of the survey areas.

Table 1.--Relative topography and density of artifacts on sectors of coastline at Macquarie Island.

Sector	Length of coastline (km)	Open beach (%)	Density of artifacts (items/km)	(items/km open beach)
1	4	25	2.5	10
2	16	38	12.2	32.5
3	16	16	19.4	124
4	8	44	39.0	89.1
5	5	20	13.8	69
6	8.5	24	11.6	45.5
7	36	67	0.6	0.9

artifacts/km coastline. Densities of artifacts varied over the island, with the greatest found in sector 4 (39 items/km) and the least (0.6 item/km) on the east coast (Table 1). Plastic items were most abundant, accounting for 60% of all objects. A wide variety of plastic items was recorded. Containers and bottles of various shapes, sizes, and uses were common, while fragments from degrading bottles and polystyrene pieces of various sizes were ubiquitous. Plastic bottles and containers made up 28% of plastic artifacts, while expanded polystyrene and other foamed products contributed 13% of plastic items. Miscellaneous small plastic pieces, including fragments of a size easily ingested by birds, made up 26% of plastic objects. Metal objects contributed 34%, while glass and miscellaneous items such as cork, hemp, cloth, and wax contributed 6% (Table 2). Objects of fisheries origin (buoys, ropes, and netting) accounted for 47% of all stranded artifacts, 29% of all plastic objects, and 89% of all metal objects.

Fishery Debris

A variety of objects originating from fisheries was recorded, including artifacts from both trawl fisheries (eastern European), and longline fisheries (predominantly Japanese). Common items included plastic and metal head line floats from trawl nets, and longline tellings (marker buoys) or surface floats (Table 3). Head line floats were often found attached to fragments of trawl net, and were occasionally found strung together with polypropylene rope in groups of up to six. Three varieties of metal head line floats were recorded: an aluminium alloy float with two separate attachment lugs bearing a Polish manufacturer's mark (55% of all metal buoys), an aluminium alloy float with a single attachment lug containing two holes (26%), and a steel float (17%). Longline tellings were usually covered in rope mesh, often with fragments of rope or mesh trailing from the floats. Ten inflatable plastic floats possibly used as longline pickup buoys or fenders were recovered. Two Japanese glass longline fishery floats, both covered in mesh, were found. Eleven

Table 2.--Numbers of artifacts found on beaches along different sectors of coastline at Macquarie Island.

Artifacts	Sector 1	2	3	4	5	6	7	Total
Plastic objects (total)	6	141	198	175	34	52	15	621
Fisheries floats	3	33	53	46	18	18	6	162
Polypropylene ropes	--	2	3	2	--	1	--	8
Netting	--	4	--	--	--	1	--	5
Expanded polystyrene	--	20	26	7	4	11	5	73
Other foamed plastics	--	--	2	1	--	1	--	4
Bags	--	3	--	--	--	--	--	3
Packing straps	--	5	4	1	--	1	--	11
Bottles and containers	--	39	54	61	6	5	3	168
Drift cards	3	3	1	6	2	--	--	15
Miscellaneous	--	32	55	51	4	14	1	157
Metal objects (total)	6	48	79	131	30	43	5	342
Fishery floats	5	40	72	117	28	39	4	305
Containers	--	4	2	6	2	1	--	15
Aerosol cans	--	3	3	8	--	1	--	15
Satellite buoys	--	--	1	--	--	2	1	4
Miscellaneous	1	1	1	--	--	--	--	3
Other objects (total)	1	9	34	12	8	5	2	71
Glass floats	--	--	--	--	1	1	--	2
Bottles and globes	1	7	25	6	3	2	1	45
Cork objects	--	--	1	--	--	2	--	3
Hemp rope	--	--	--	4	2	--	--	6
Bamboo	--	1	1	--	--	--	--	2
Miscellaneous	--	1	7	2	2	--	1	13
Grand total	13	198	311	318	72	100	22	1,034

fragments of rope were recorded. These were of varied length up to about 30 m. Two fragments of teased nylon antichafing blankets were collected, as well as a 2-m fragment of 120-mm stretched mesh codend.

Origin of Artifacts

The country of origin of some of the artifacts could be identified. Most objects were of South American, eastern European (mainly Polish or Russian), or oriental origin (Table 4). The items of fishing debris were identified from writing on floats. Country of origin of fishing floats does not necessarily imply use by that country's fishing fleet, as several nationalities are known to use Japanese floats, although Japanese floats produced for the export market are imprinted in English (R. Burbury pers. commun.). The metal head line floats (Table 3) were of the variety used by

Table 3.--Artifacts which originated from fishing activity washed ashore at Macquarie Island.

Fishing activity debris	Number
Longline fishery debris	
Longline tellings (plastic)	72
Dahn-pole floats	1
Polystyrene surface floats	4
Inflatable pickup floats	10
Trawl fishery debris	
Plastic head line floats	79
Metal head line floats	297
Steel bobbins	8
Trawl-web netting fragments	4
Ropes	11
Antichafing blanket	2
Codend net fragment	1
Miscellaneous fishery debris	
Fender or marker buoy	5
Plastic top buoys (use unknown)	6

the Russian and Polish trawl fisheries, although 55% of these bore a Polish manufacturer's mark. Plastic head line floats included 52 of Russian origin and 2 varieties of Argentinian float (brand names Moscuzza and Arex, Table 4). Plastic containers and other litter were identified to country of origin where brand names or manufacturers' names could be read. Most of these artifacts were discarded containers of household consumables such as detergents, shampoos, drinks, aerosol cans, and general food items.

Fifteen plastic drift cards were collected from the coast of Macquarie Island. Of these 13 were of South African origin (Shannon et al. 1973; Lutjeharms et al. 1988), and 2 were Australian.

State of Decay

Plastic objects were found in various stages of decay, ranging from almost pristine with easily discernible printing and little or no sign of ultraviolet degradation to brittle and disintegrating. Most plastic fishing floats had broken lugs, and 32% were in fragments. Generally, fishing floats made of aluminium alloy showed little sign of degradation, although some had broken lugs while others showed signs of pitting. All steel objects were corroded. Many plastic bottles were disintegrating into small fragments, and this type of fragment contributed 46% of miscellaneous plastic objects (Table 2). Most glass bottles were whole.

Table 4.--Countries or regions of origin of artifacts found on Macquarie Island. Where regions only are used, sources of the objects could not be identified more specifically.

Country or region	Fisheries gear	Plastics	Other litter
South America	1	3	4
Argentina	17	4	1
Orient	23	--	--
Japan	37	10	4
China	3	1	--
Scandinavia	1	4	1
Germany	--	1	4
Switzerland	--	--	1
Britain	--	2	2
France	2	--	3
Eastern European	168	--	--
U.S.S.R.	51	3	12
United States	--	2	--
Australasia	--	2	9
South Africa	--	--	13

DISCUSSION

The artifacts stranded at Macquarie Island can have either local or oceanic sources. Some objects may have resulted from the activities of the ANARE station, as rubbish has been dumped in the isthmus area in the past. However, in recent years all plastic, metal, and glass refuse generated by the station has been removed from the island. Thus, in the essential absence of a local source, the stranded artifacts were all derived from oceanic sources, that is, they drifted to the island from distant source-regions.

Macquarie Island lies just to the north of the Antarctic Polar Front (Tchernia 1980). The main oceanic drift pattern which influences Macquarie Island is the West Wind Drift, which has a slight northerly component (Shannon et al. 1973; Lutjeharms et al. 1988). Within that westerly drift, mean surface drift speeds in the Southern Ocean at the latitude of Macquarie Island have been determined at between 14.6 and 19.0 cm/sec (Shannon et al. 1973; Bye 1988; Lutjeharms et al. 1988). Drifting buoys show a tendency to accumulate in areas corresponding to the historic locations of the various frontal systems of the Southern Ocean (Lutjeharms et al. 1988), and the pattern of drift towards these fronts is also demonstrated by the amount of plastic litter which tends to accumulate there (Gregory et al. 1984; Galt 1985; Day and Shaw 1987). Most litter stranded on Macquarie Island would have come from the west (e.g., South American debris), and the influence of the West Wind Drift together with the prevailing westerly winds would explain the high incidence of strandings on the west coast of the island and the low incidence on the east coast. The northerly component of the West Wind Drift, the tendency of floating material to accumulate at oceanic fronts, and the movement of Antarctic Water toward Macquarie Island in winter, suggest debris stranding at Macquarie Island may originate with ships operating both to the north and to the south of the Antarctic Polar Front.

The debris stranded at Macquarie Island originated in several countries. However, the country of origin of artifacts does not necessarily represent the drift tracks, as much of this debris is probably derived from the fishing fleets and other vessels operating in the Southern Ocean. It is possible that some articles with Spanish writing originated on the coast of South America or from vessels operating in that region. Driftwood originating in South America (predominantly *Nothofagus* spp.) has been reported from South Georgia (Lewis Smith 1985), and from Macquarie Island (Barber et al. 1959).

The significant contribution of fisheries-related objects to the debris on Macquarie Island is similar to that found on other islands in the Southern Ocean (Burton and Williams 1985; Ryan 1987b; Ryan and Watkins 1988), and to the situation on remote beaches in the Northern Hemisphere (Merrell 1984). Fishing gear can become a marine pollutant as a result of accidental loss or deliberate dumping. Fragments of net, line, and associated gear can be lost through snagging, but fishing gear which is worn or damaged beyond further use is often discarded at sea (Pruter 1987). Although vessels have little control over damage to fishing gear, it is possible to control the amount of gear which is actively discarded.

There are two major types of fisheries which operate in the Southern Ocean: bottom and midwater trawling and ocean longlining. The fisheries-related debris which washed ashore on Macquarie Island originated in both these fisheries. Trawl fishing operations for fish and krill in the Southern Ocean are dominated by the U.S.S.R. and Japan, with lesser amounts taken by Poland and the German Democratic Republic. For fish and krill, significant fisheries occur in the Atlantic Ocean sector around South Georgia and the Scotia Arc, and for fish only, around Iles Kerguelen in the Indian Ocean sector (Northridge 1984; Williams 1988). The high number of metal head line floats, Russian plastic head line floats, and other trawl gear (Table 3) were probably lost from the eastern European trawlers operating in these areas, with the majority of fishing gear coming from Iles Kerguelen as they are not only closer to Macquarie Island than is South Georgia, but also closer to the Antarctic Polar Front. Some of the plastic head line floats were of Argentinian origin, and probably came from offshore trawling near the coast of South America. These, along with other South American artifacts, were probably carried to Macquarie Island by the West Wind Drift. Fishing gear from longline fisheries was probably lost from Japanese, Taiwanese, or Korean vessels operating to the north of the Antarctic Polar Front, and possibly quite close to Macquarie Island at times (Robins 1985).

The density of stranded artifacts along a shoreline is determined by a number of geographical factors including beach orientation relative to prevailing currents and winds, offshore reef structure, beach gradient and texture, and local tide and storm effects (Ryan 1987b). The overall density of artifacts on Macquarie Island (11/km) was less than the densities reported for Prince Edward Island off Africa (32/km), Gough Island (14/km), Tristan da Cunha and Inaccessible Island (from 292 to 807/km; all Ryan 1987b), or Amchitka Island in Alaska (193 to 499/km; Merrell 1980). These differences may be due, in part, to sampling methods, as the surveys above concentrated on particular beaches whereas this survey took into account the entire coastline of Macquarie Island. Surveys of stranded artifacts are often concentrated in areas of noticeably high density with the aim of determining (through repeated surveys) the accumulation rate of debris at one site over time. This may result in inflated estimates of density and make intersite comparisons of density difficult or even invalid. The almost north-south orientation of Macquarie Island results in one coast being exposed to prevailing westerly winds and currents, while the other coast is relatively sheltered. Thus, densities of artifacts in different parts of the island vary widely (Table 1). The low density of artifacts on the east coast (0.6/km) is probably due to the prevailing westerly winds, and surveys from other subantarctic islands have shown that quantities of stranded litter are greatest on the windward (westward) shores (e.g., Gregory 1987; Ryan 1987b). Despite the difficulties of interisland comparisons, the density of stranded litter on Macquarie Island appears to be less than on islands in the Atlantic and Indian sectors of the Southern Ocean (Ryan 1987b), and much less than for remote areas of Alaska (Merrell 1980). This is probably related to the proximity of fishery operations, with most fishing occurring far to the west of Macquarie Island.

The high proportion of plastics among stranded artifacts at Macquarie Island is similar to that reported on other islands of the Southern Ocean (Ryan 1987b) and elsewhere (e.g., Merrell 1980, 1984; Pruter 1987; Shiber 1987). The high incidence of plastics in stranded litter is probably due to the increased use of plastics over the last few decades, particularly for packaging, and the slow rate at which plastics degrade. Surveys in the North Sea and off the coasts of northwest Europe have shown that most marine litter is primary or secondary packaging, particularly plastic bottles, the majority of which originate with the disposal of garbage by ships at sea (Dixon and Dixon 1981, 1983). Plastics decay slowly, with little ultraviolet degradation occurring at sea (Shannon et al. 1973).

The impact of stranded artifacts on local fauna and flora is difficult to assess. Plastic particles are commonly ingested by seabirds but most ingestion probably occurs at sea (Ryan 1987a). Some seabirds at Macquarie Island ingest small fragments of plastic, some of which may have been ingested on shore (Slip pers. observ.).

The density of entanglement-type litter stranded at Macquarie Island is less than densities reported for the Northern Hemisphere (Merrell 1980, 1984). Although the southern elephant seal, *Mirounga leonina*, and fur seal, *Arctocephalus* spp., populations have been closely monitored over the last 5 years, to our knowledge there have been no recent reports of entanglements in these species at Macquarie Island, although one fur seal was sighted with a plastic packing strap collar in 1975 (G. Copson pers. commun.). Greater concentrations of trawl debris occur in areas of concentrated fishing effort (e.g., Fowler 1987), and as the major fishing effort in the Southern Ocean is far to the west of Macquarie Island, the densities of entanglement debris may be low enough to cause little impact on the marine mammals. However, these species are wide ranging, and fatal entanglements of marine mammals at sea are believed to far outnumber those where the animal reaches shore (Fowler 1987). Thus, once debris is stranded it apparently has little impact on the marine mammals, and ingestion of small plastic fragments by some bird species is likely to be the major impact on local wildlife. The impact of these artifacts is therefore likely to be much greater prior to their stranding.

The amount and variety of stranded artifacts at Macquarie Island demonstrate the preponderance and ubiquity of plastics. The hazards posed to wildlife and shipping by marine litter demonstrate the need for active programs to prevent littering at sea and on land.

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